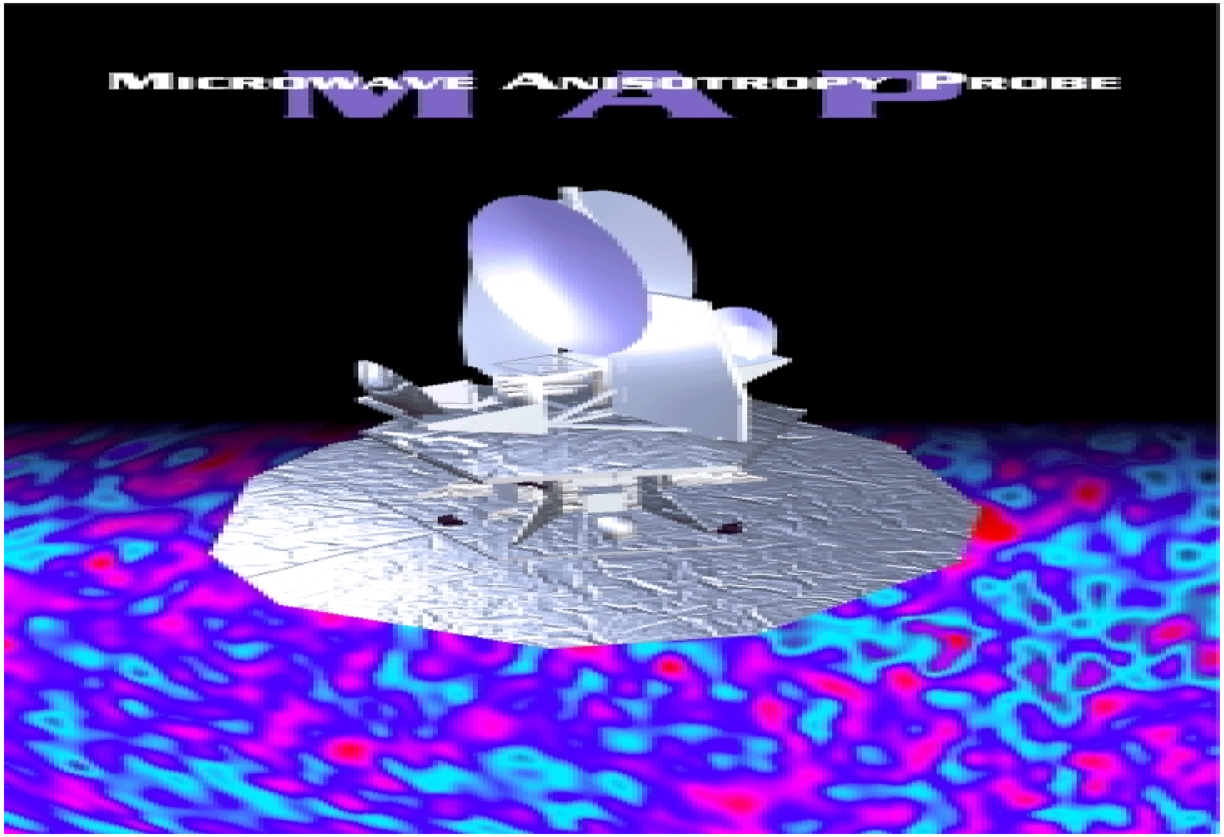
MAP Flight Operations Review



April 4,5 & 6, 2000

Agenda

April 04, 2000

TIME	TOPIC		PRESENTER
08:30	Introduction		Coyle
08:45	Overview		
		Science	Hinshaw
		Mission	Citrin
10:45	Observatory Subsystems Operations		
		ACS	Ward
		Sensor Calibration	Harman
11:45	Lunch Break		

Agenda

April 4, 2000 (Continued)

TIME	TOPIC		PRESENTER
12:45	Observatory Subsystems Operations (Continued)		
		Propulsion	Davis
		Thermal	Brown
		Instrument	Kogut
		C&DH	McCabe
		RF	Powers
		Power	Wingard
		FSW	Marquart
		Deployment	Stewart
02:45	Ground System		Coyle
04:00	DSN Operations		Landon

Agenda

April 5, 2000

TIME	TOPIC		PRESENTER
08:30	Launch Site Operations		Stafford
09:30	Nominal Operations		
		Detailed Mission Timelines	Coyle
		Procedure Status	Miller
		Mission Planning	
		Post-Pass Data Analysis	Gonzales
		Ground System Autonomy	
		Science Data Processing	Hinshaw
11:30	Lunch Break		
12:30	Trajectory		Cuevas
			Andrews
			Mesarch
			Davis

Agenda

April 6, 2000 (first round of the Masters)

TIME	TOPIC	PRESENTER
08:30	Constraints & Contingencies	Bay
	Fault Tree	
	S/C Autonomy	
10:30	Mission Readiness Testing	Blahut
11:30	Lunch Break	
12:30	On-orbit Management	Coyle
	FSW Maintenance	Marquart
03:00	Conclusion	Coyle

Introduction

FOR Review Panel

- Bill Mack - Flight Assurance (Chairman)
- Frank Snow - Flight Projects
- Bill Worrall - Flight Projects
- John Catena - Engineering
- Landis Markley - Engineering
- John Wolfgang - Space Science
- J.B. Joyce - JHU/FUSE
- Kathleen Howell - Trajectory
- Martin Lo - Trajectory
- Peter Sharer - Trajectory

Charter

- Evaluate the readiness of the MAP Ground System and Mission Operations Preparations to support the MAP launch, early orbit Checkout and L2 operations

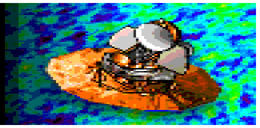
- Evaluate the MAP Trajectory Design. Confirm that the mission requirements are fully understood, the design is adequate to meet the requirements, and that the verification plan is sufficient to ensure the success of the MAP mission. (Delta Trajectory Design Peer Review)

Scope

- Launch, in-orbit checkout (IOC) and nominal operations planning
- Trajectory design and maneuver planning
- Contingency planning
- Ground System hardware and software
- Documentation and configuration management
- Test and verification
- Operations staffing and training

MICROWAVE ANISOTROPY PROBE

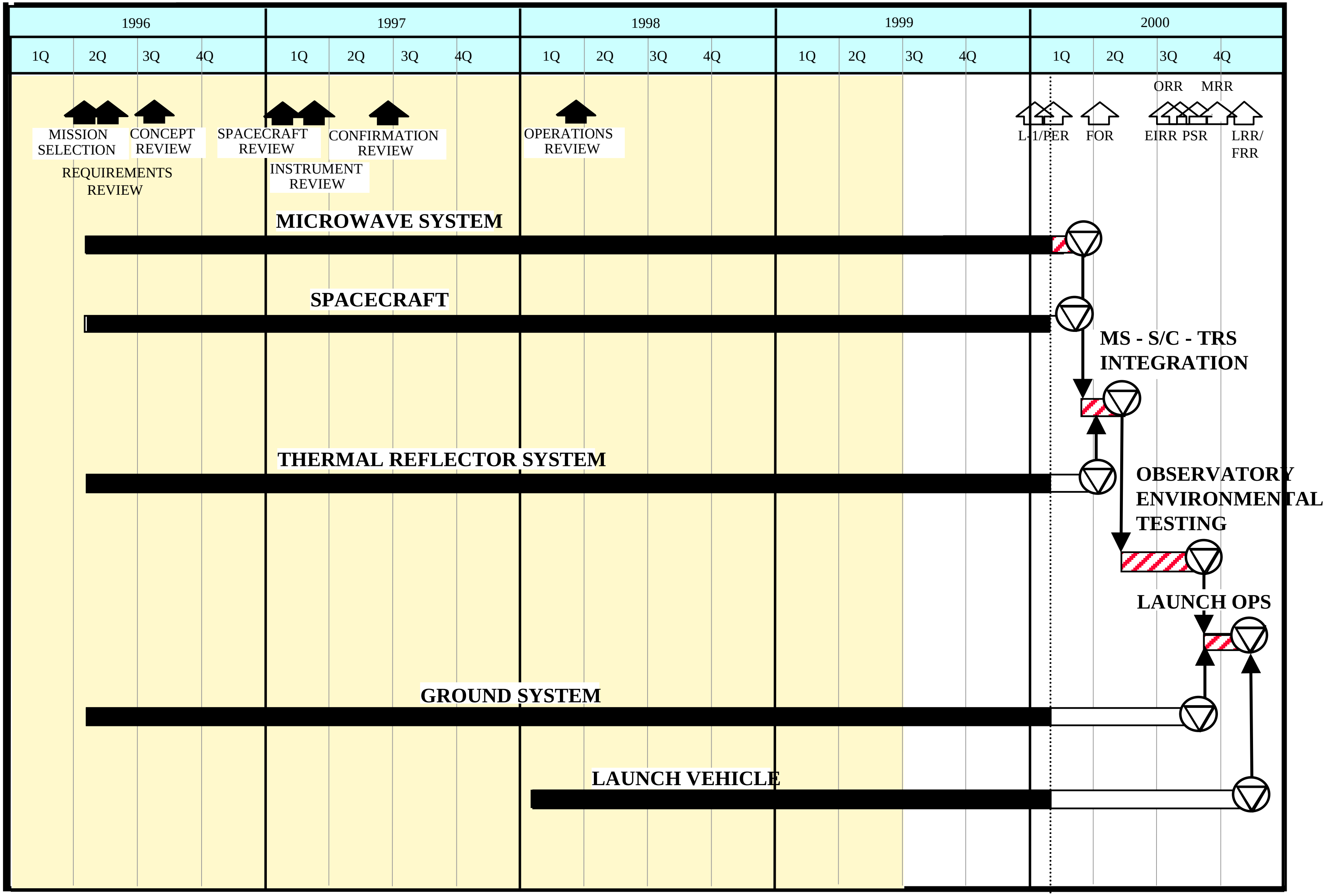
MAP



OBSERVATORY INTEGRATION AND TEST

MICROWAVE SYSTEM ENVIRON TESTING	1/04/00	3/12/00
MICROWAVE SYSTEM TO S/C INTEGRATION	3/13/00	4/4/00
COMPREHENSIVE PERFORMANCE TEST	4/5/00	4/14/00
INTEGRATE TRS & VERIFY ALIGNMENT	4/15/00	4/27/00
INTEG SUNSHIELD MASS PROPERTIES	4/28/00	5/16/00
EMI TESTS	5/17/00	5/27/00
SINE VIB/ACOUSTICS SHOCK/PAF TESTS	5/30/00	6/15/00
ALIGN; DEPLOY/ REMOVE SUNSHIELD	6/16/00	6/24/00
THERMAL VACUUM THERMAL BALANCE	6/26/00	8/23/00
ALIGNMENT VERIFIC. FLIGHT BATTERY INT	8/24/00	8/29/00
COMPREHENSIVE PERFORMANCE TEST	8/30/00	9/7/00
PRE-SHIP PREPARATIONS	9/8/00	9/14/00
TRANSPORT TO KSC UNPACK & SET-UP	9/15/00	9/21/00
COMPREHENSIVE PERFORMANCE TEST	9/22/00	10/2/00
INTEG. SUNSHIELD & FINAL PRE-PAD TEST	10/3/00	10/12/00
LAUNCH SITE SCHEDULE RESERVE	10/13/00	10/14/00
LOAD PROPELLANT & WET SPIN BALANCE	10/15/00	10/23/00
INTEGRATION WITH DELTA THIRD STAGE	10/24/00	10/27/00
SLC-17 INTEGRATED VEHICLE OPS	10/28/00	11/07/00
LAUNCH	11/07/00	11/07/00

MICROWAVE ANISOTROPY PROBE
PROJECT MASTER SCHEDULE

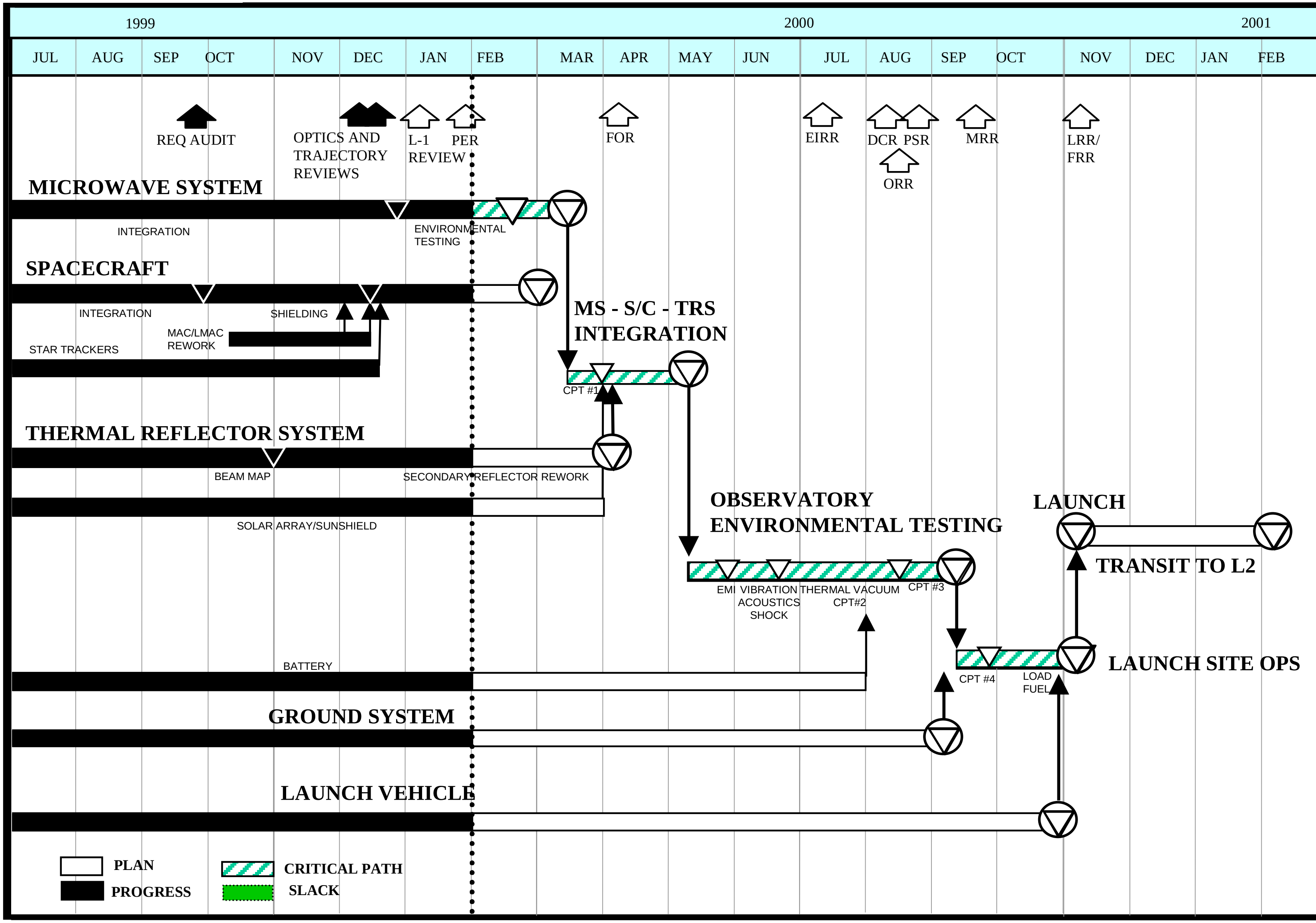


PLAN
PROGRESS
CRITICAL PATH
SLACK

APPROVED: 1/31/00
STATUS: 1/31/00

PLEASE CHECK MAP WEB SITE TO VERIFY THAT THIS IS THE CORRECT VERSION PRIOR TO USE.

MICROWAVE ANISOTROPY PROBE
MASTER SCHEDULE SYSTEM I&T



APPROVED: 2/4/00 STATUS: 1/31/00 PLEASE CHECK MAP WEB SITE TO VERIFY CORRECT VERSION PRIOR TO USE.

Science & Spacecraft Overview

Gary Hinshaw

Liz Citrin

Science Overview

Gary Hinshaw
MAP Science Team

Cosmological Dynamics

- Einstein equations describe the dynamics of the scale factor *a(t):*

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}(\rho + 3p)$$

$$\left(\frac{\dot{a}}{a}\right)^2 + \frac{k}{a^2} = \frac{8\pi G}{3}\rho$$

- Energy conservation dictates:

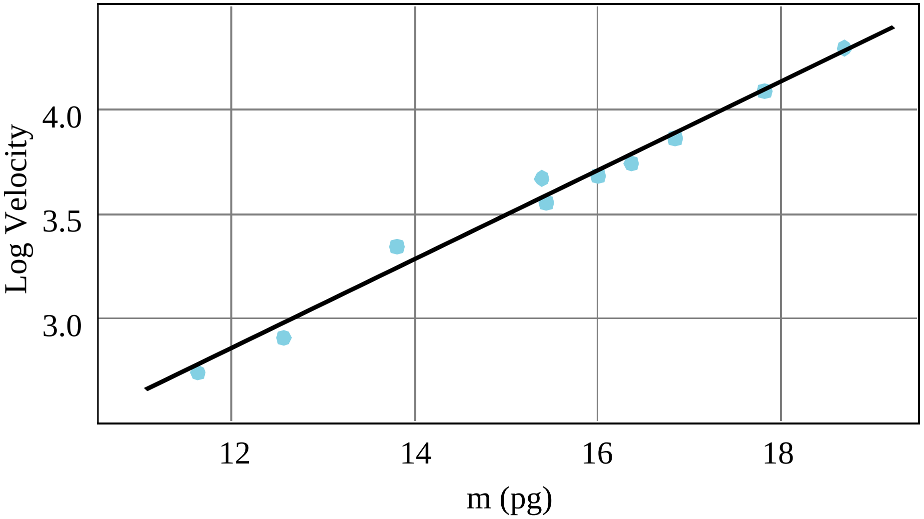
$$\frac{d}{dt}(a^3\rho) = -p\frac{d}{dt}a^3$$

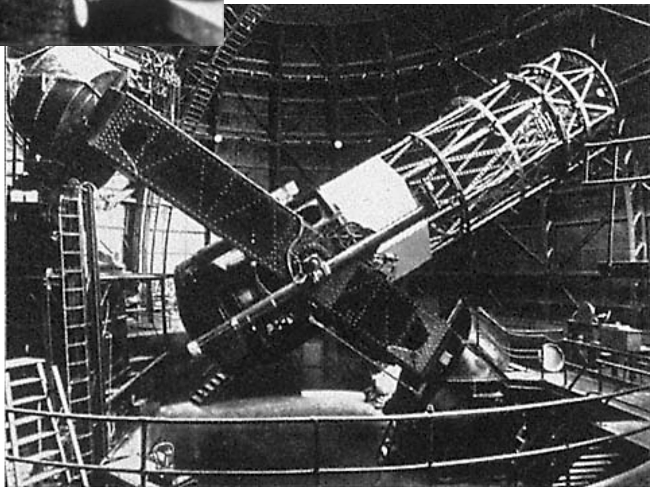
- Three types of matter:

$$\begin{array}{lll} cold: & p \approx 0 & \rho \propto a^{-3} \\ hot: & p = \frac{1}{3}\rho & \rho \propto a^{-4} \\ lambda: & p = -\rho & \rho = const. \end{array}$$

Discovery of the Expanding Universe

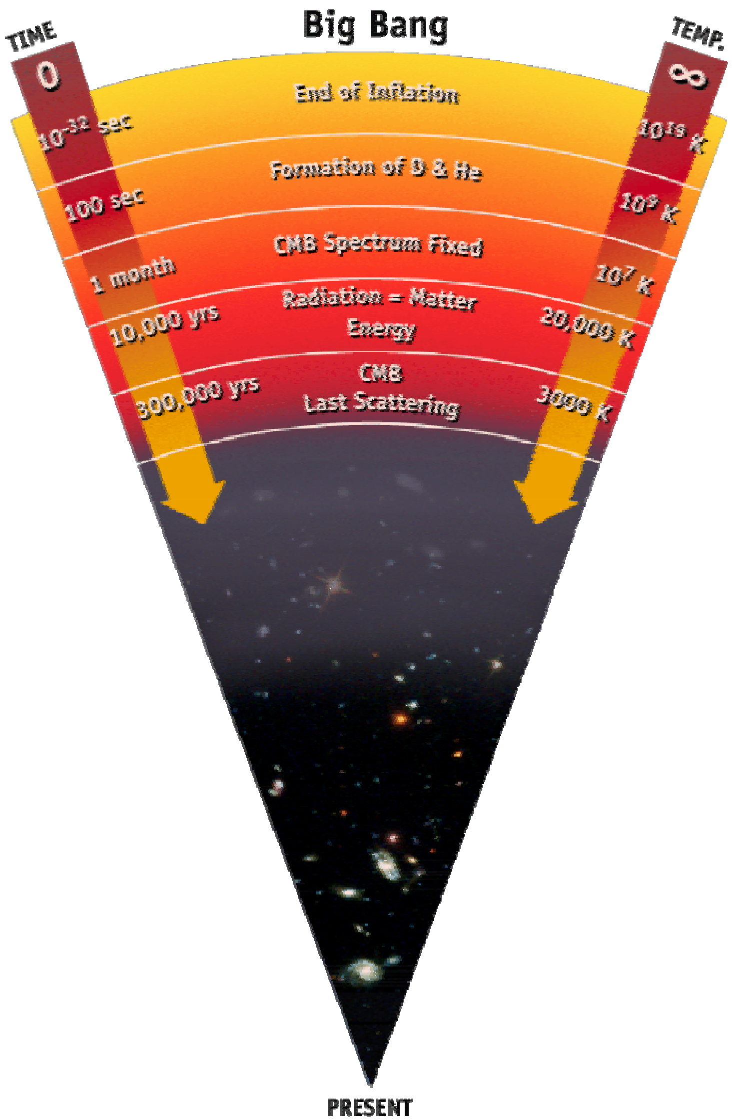
Edwin Hubble





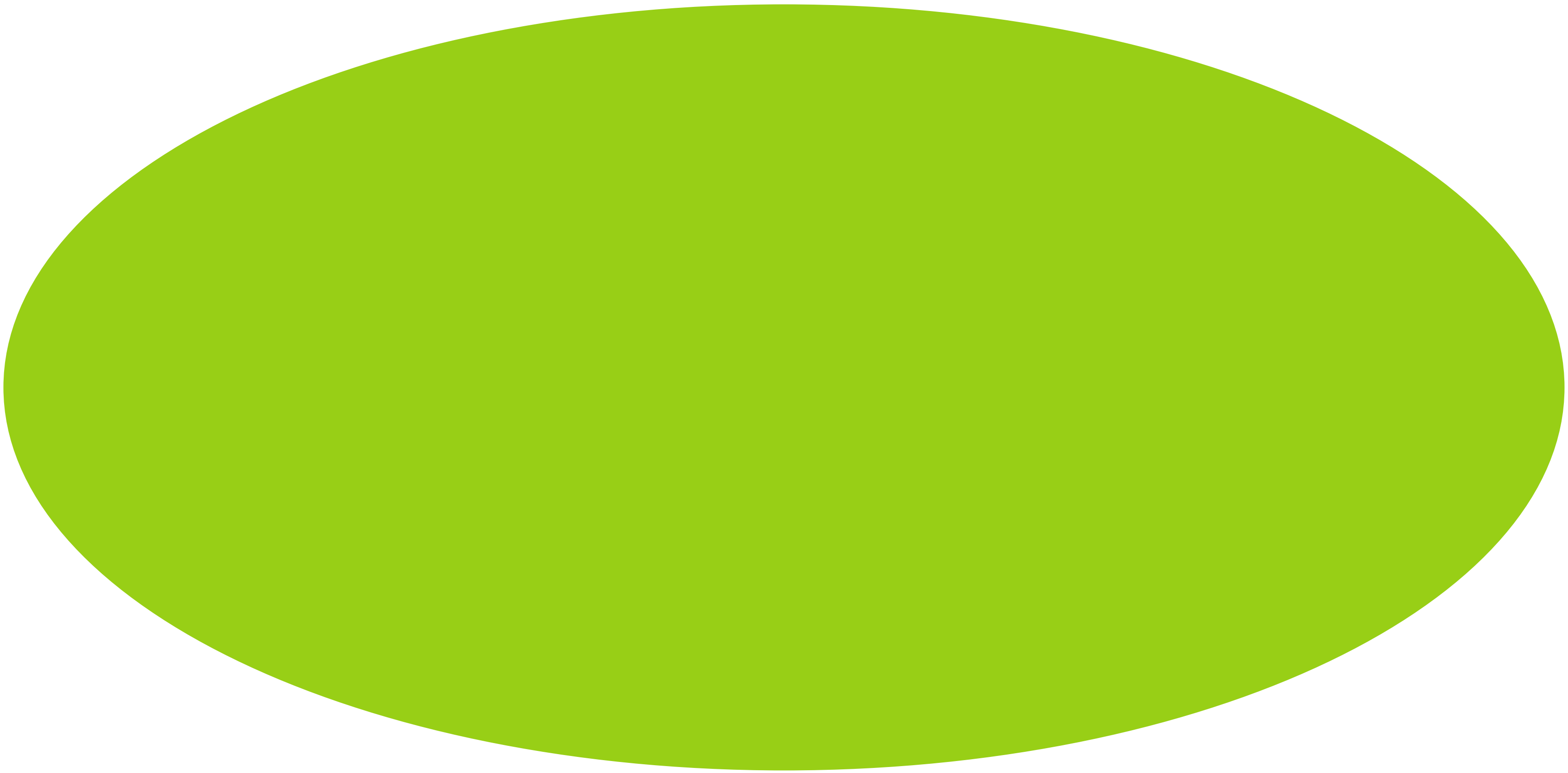
Mt. Wilson
100 Inch
Telescope

Cosmic History



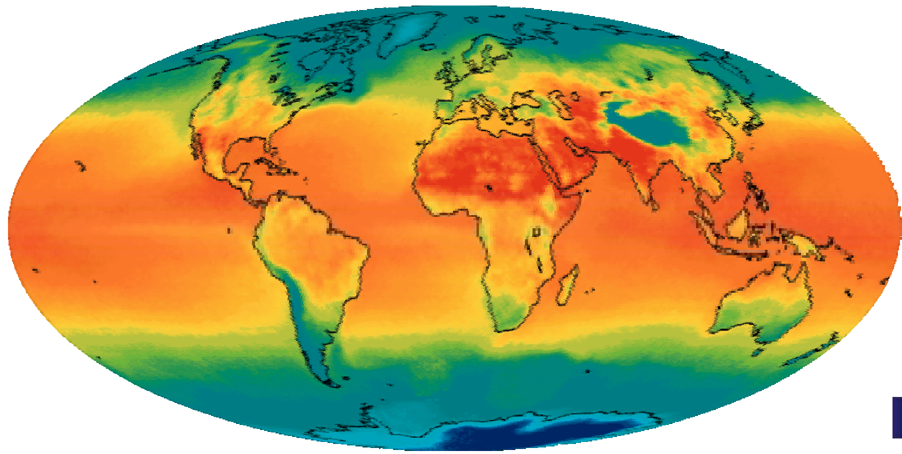
MAP990011

Isotropy of the Cosmic Microwave Background

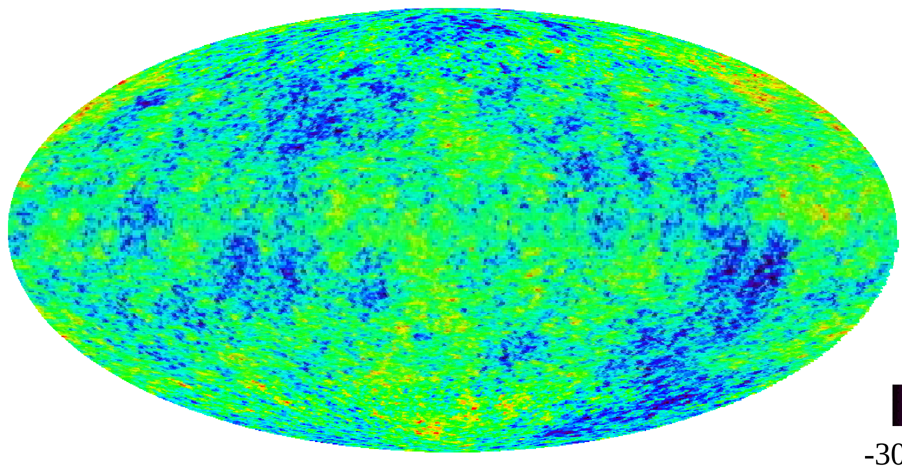


Mapping Temperature

Flight Operations Review



-63° -13° 37°
Centigrade
JUNE 1992



-300 +300
microKelvin
300,000 YearsABB

MAP990042

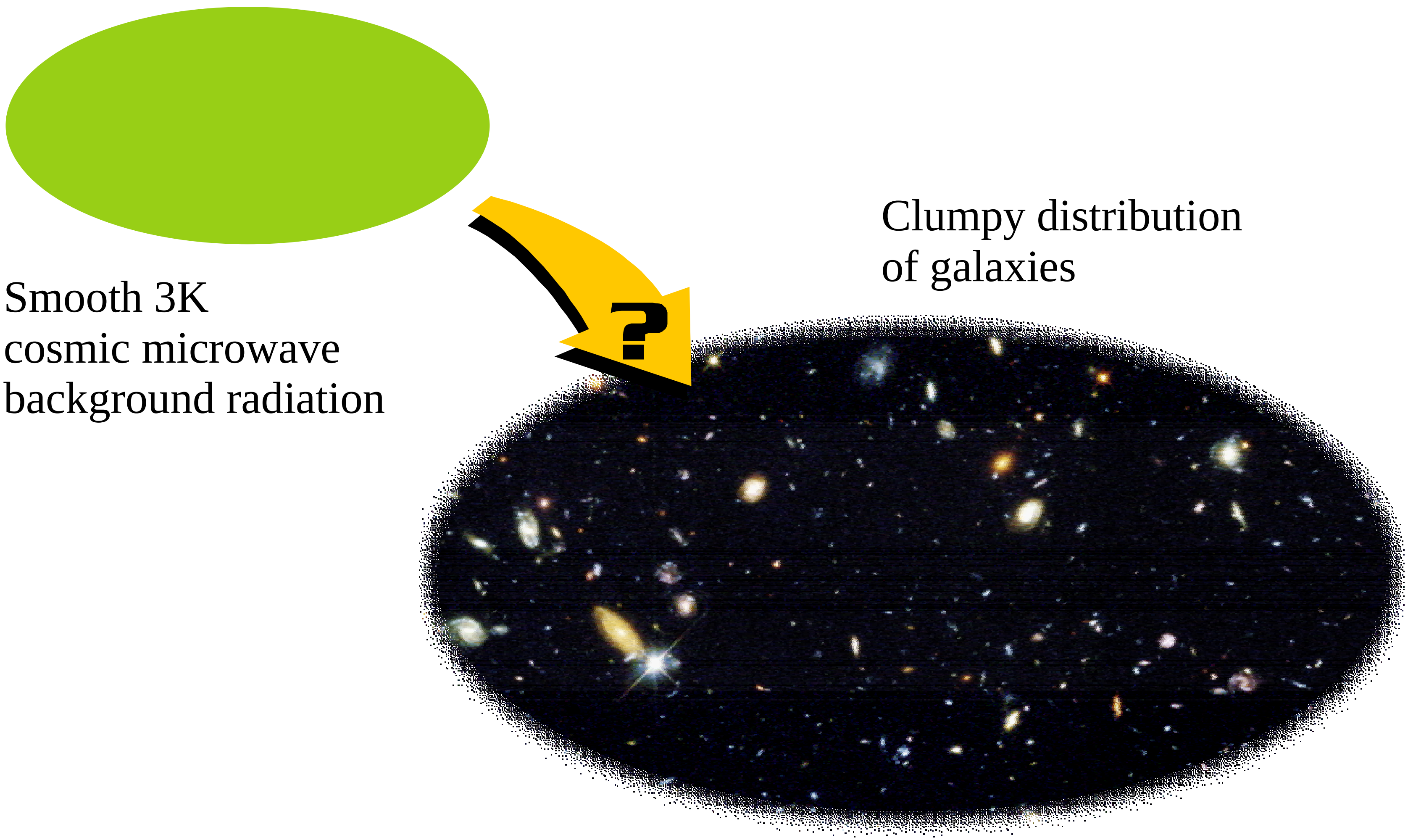
Science Questions

How did structures of galaxies form in the universe?

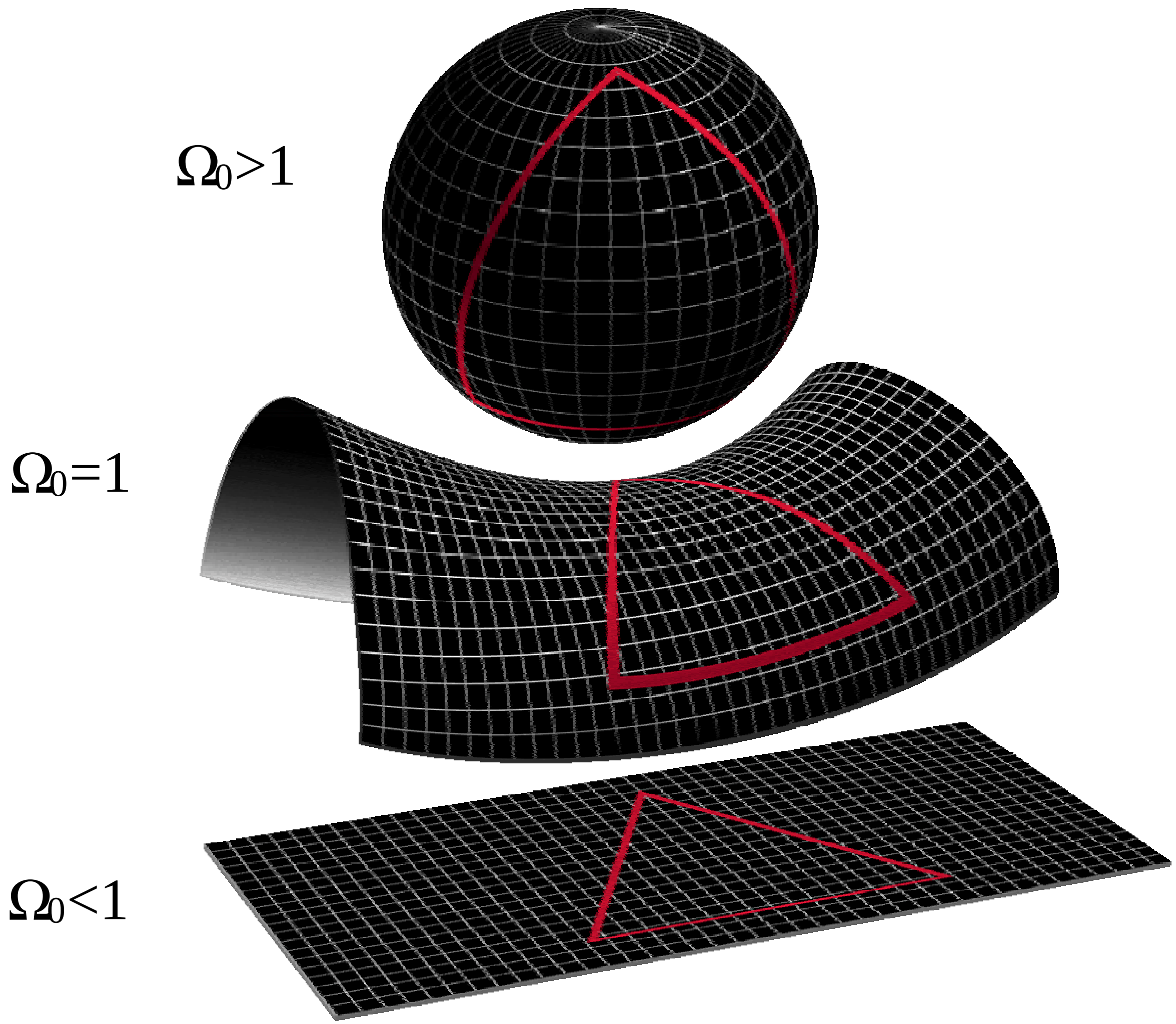
What are the values of the key parameters of the universe?

When did the first galaxies form?

Structure Problem

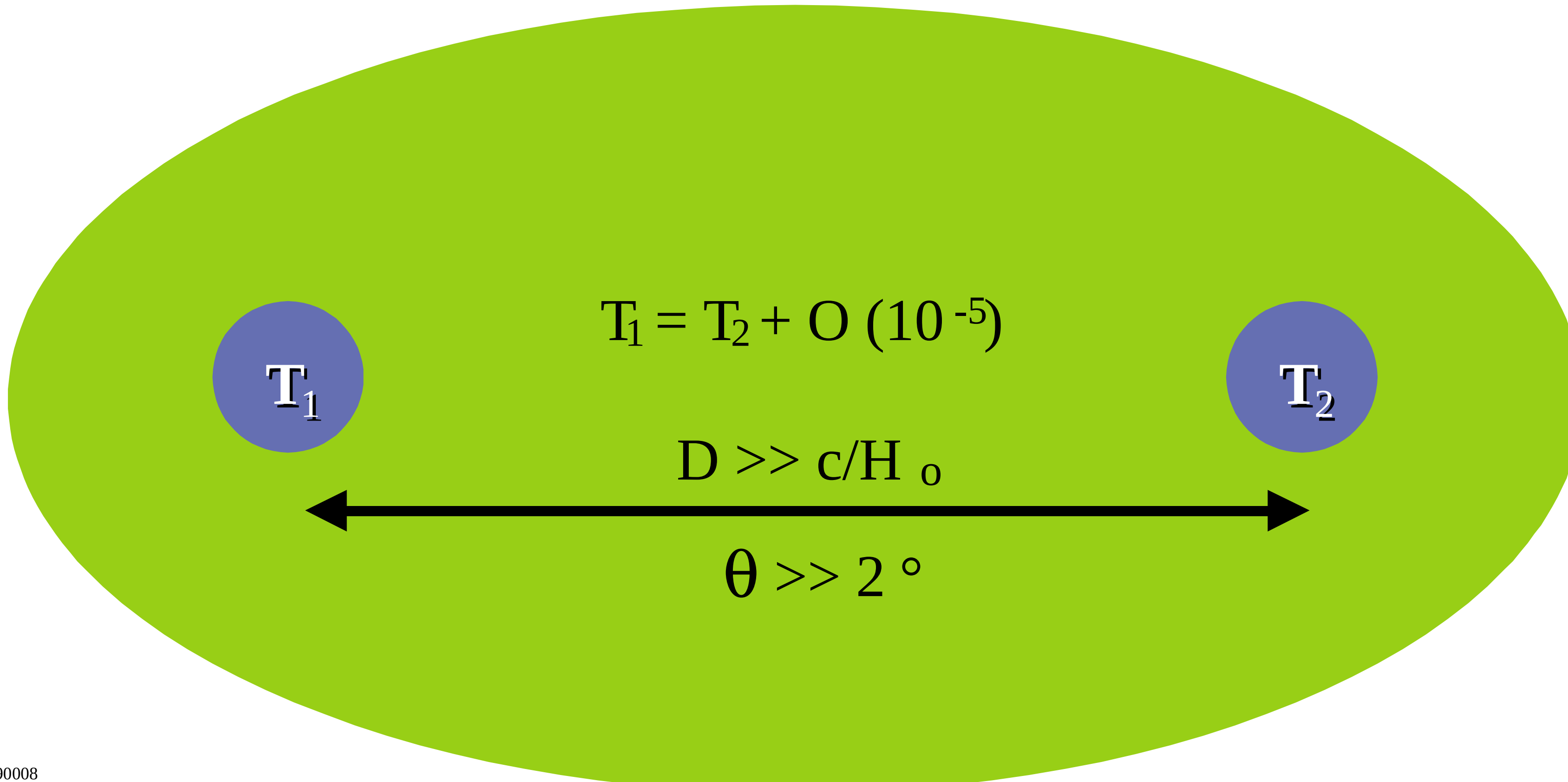


Mass Density / Geometry of the Universe



The Horizon Problem

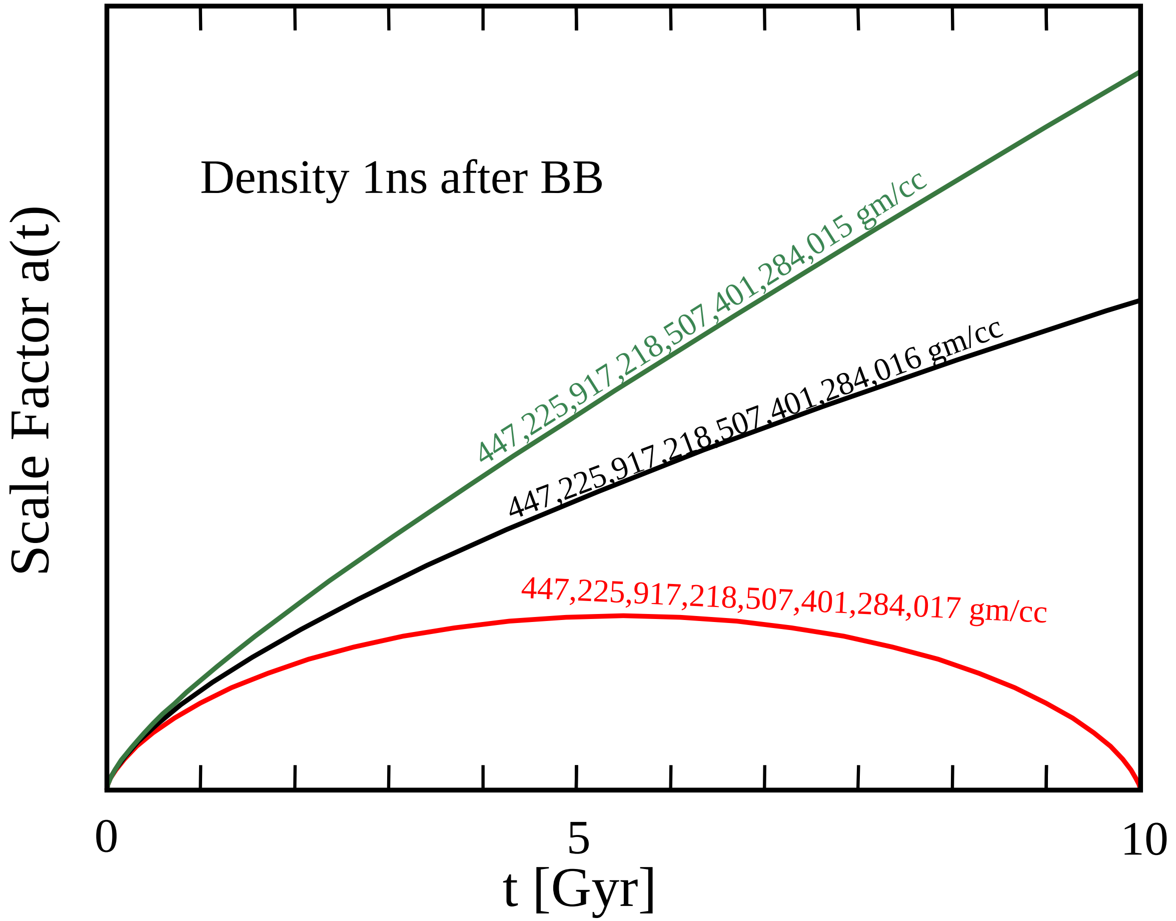
Why is the cosmic microwave background temperature so uniform on scales >2°?



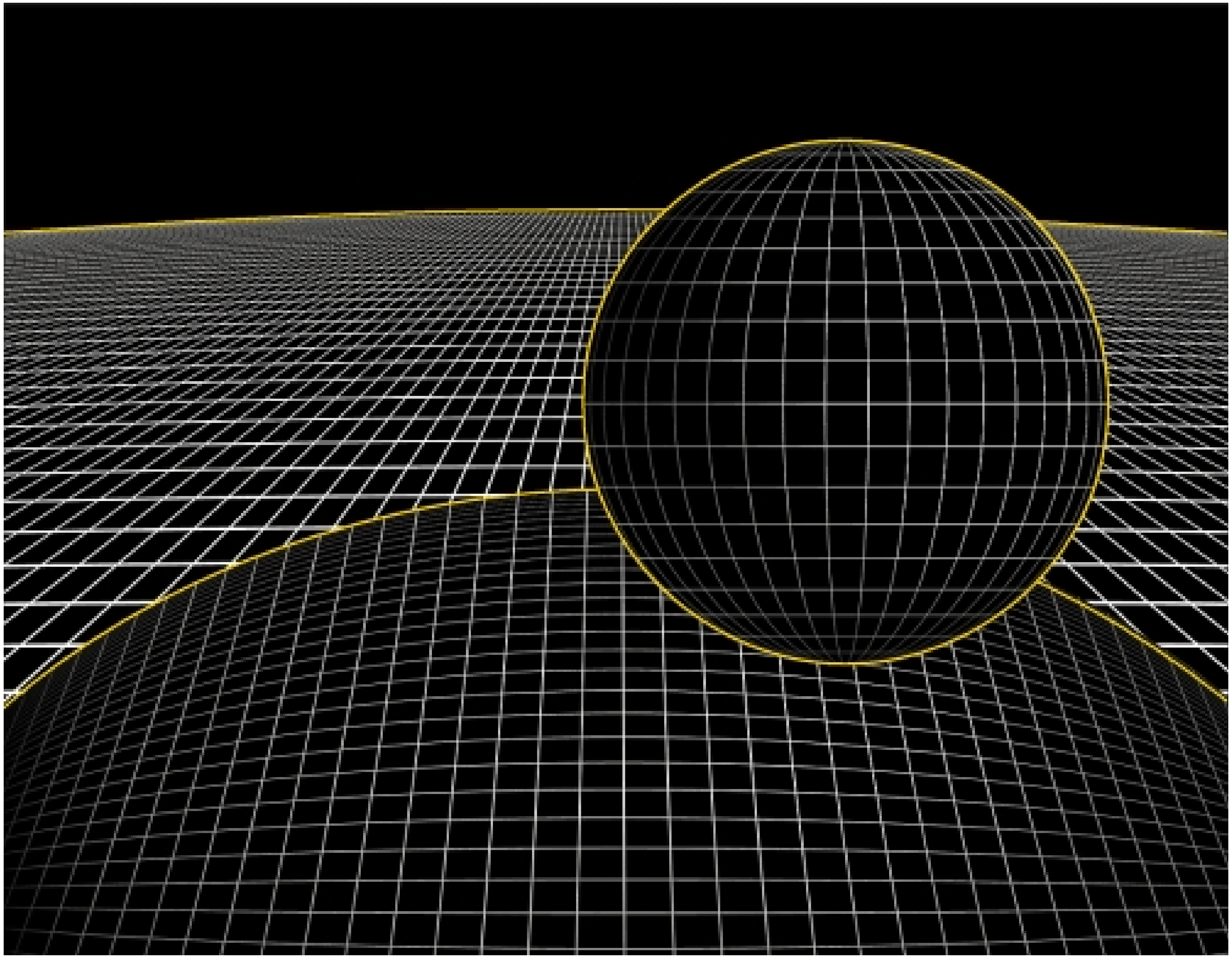
The Flatness Problem

Why is the universe anywhere close to $\Omega_0 = 1$ now?

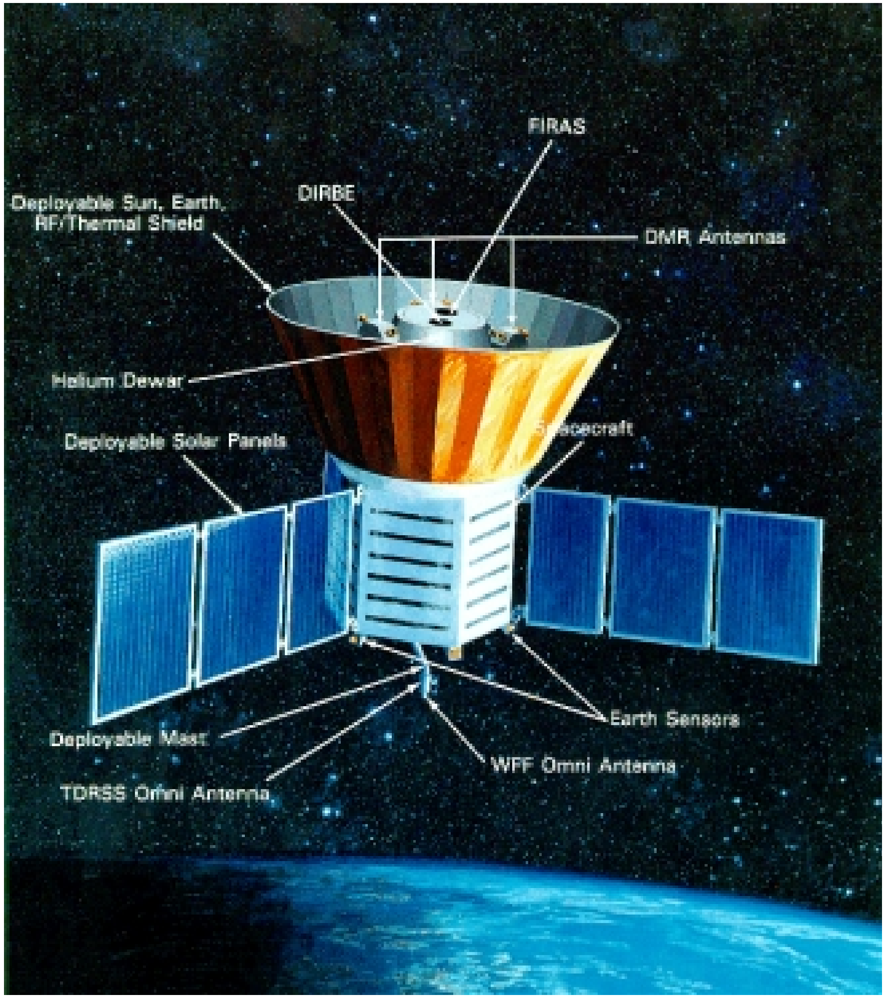
$\Omega_0 = 1$ is an unstable stationary point.



Inflate to Locally Flat Space



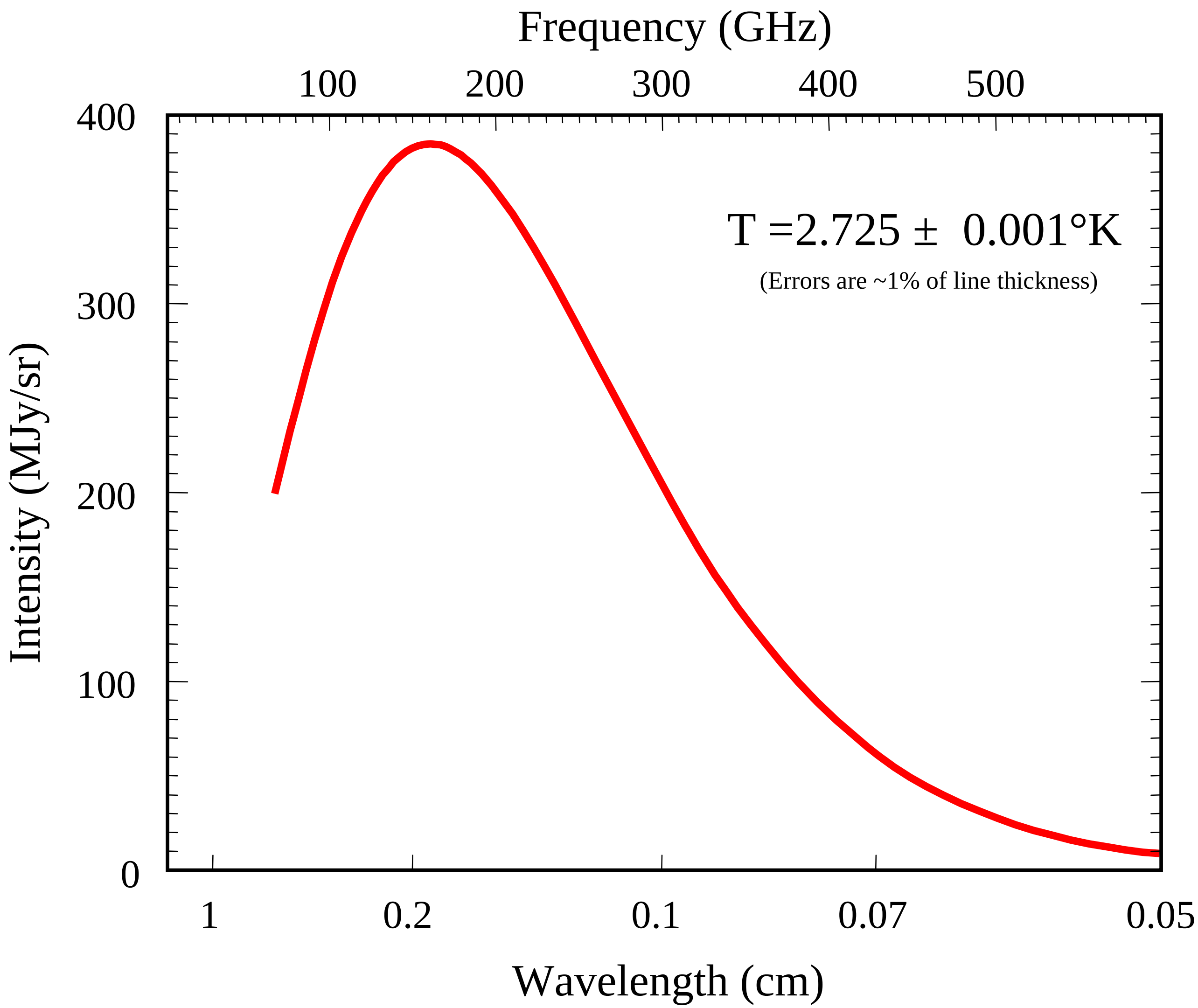
COBE Results



What Did We Learn From COBE???

Spectrum of the CMB

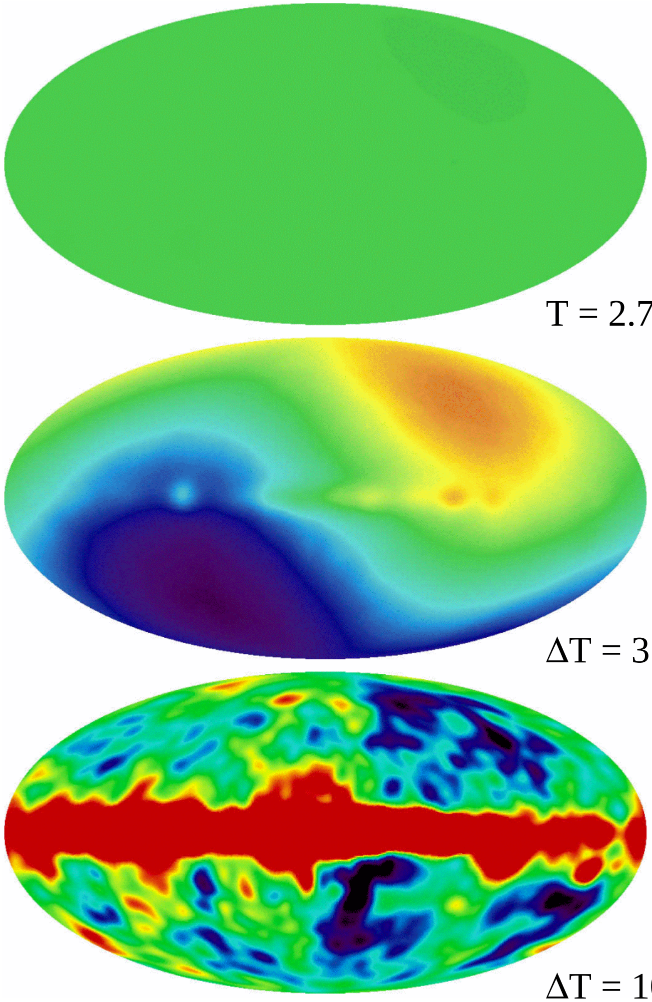
Flight Operations Review



MAP990015

COBE CMB

Flight Operations Review



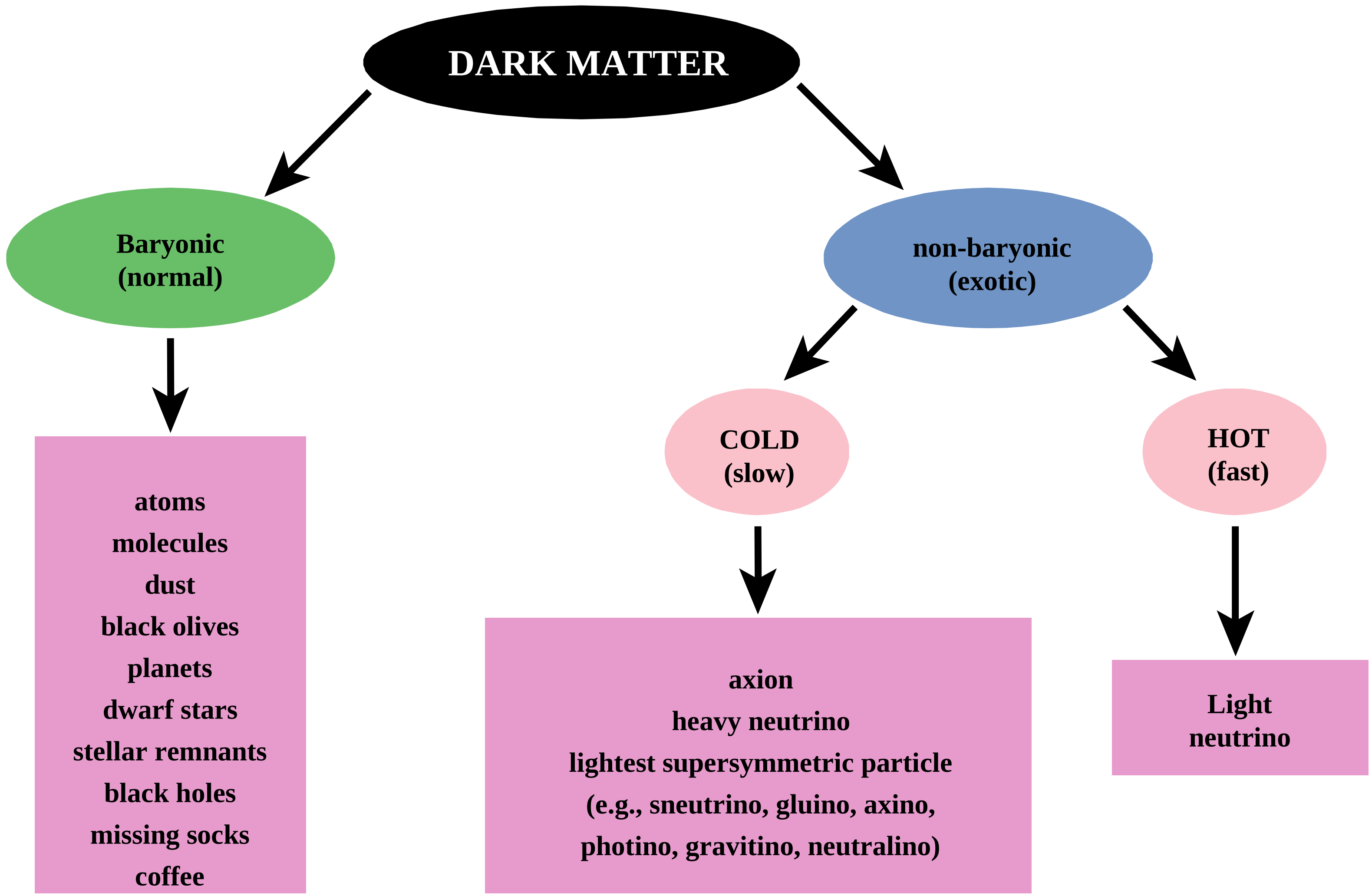
T = 2.725 K

$\Delta T = 3.353$ mK

$\Delta T = 100$ μK

MAP990063

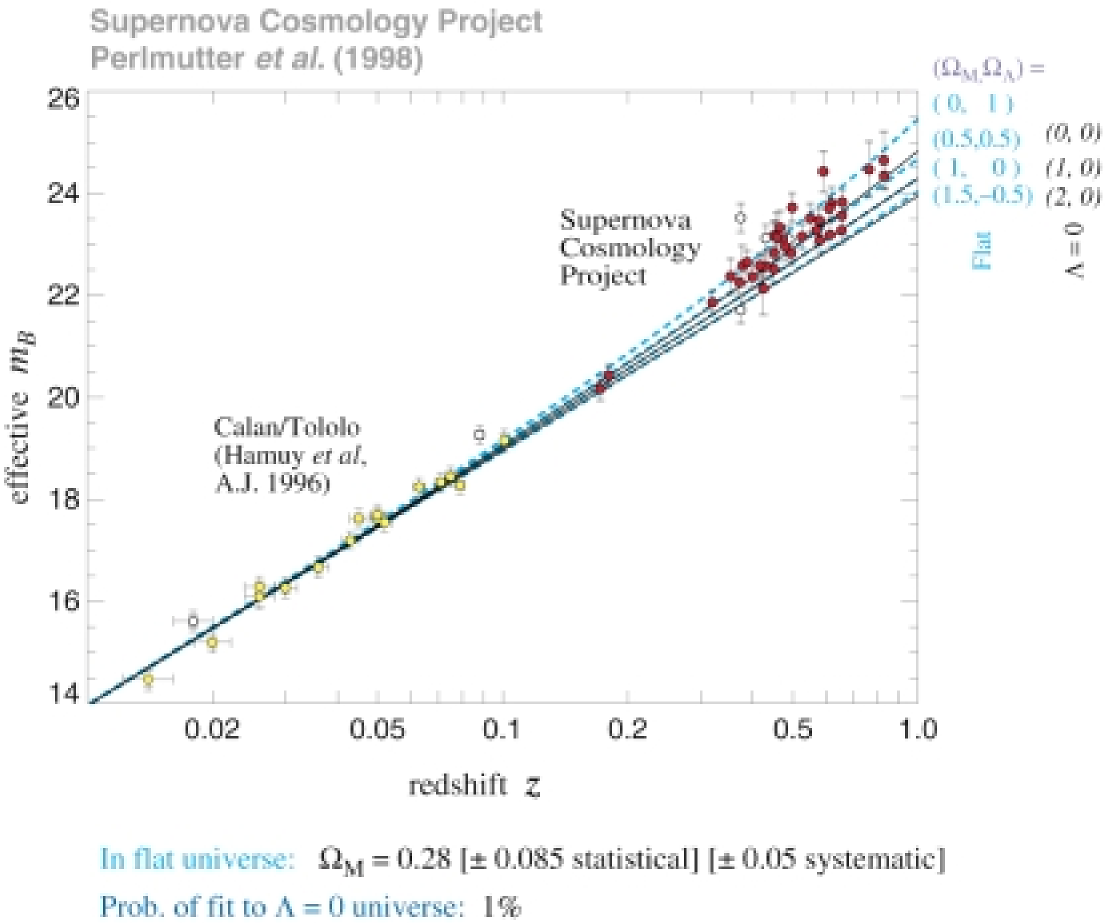
Dark Matter Taxonomy



MAP990013

Supernovae Cosmology

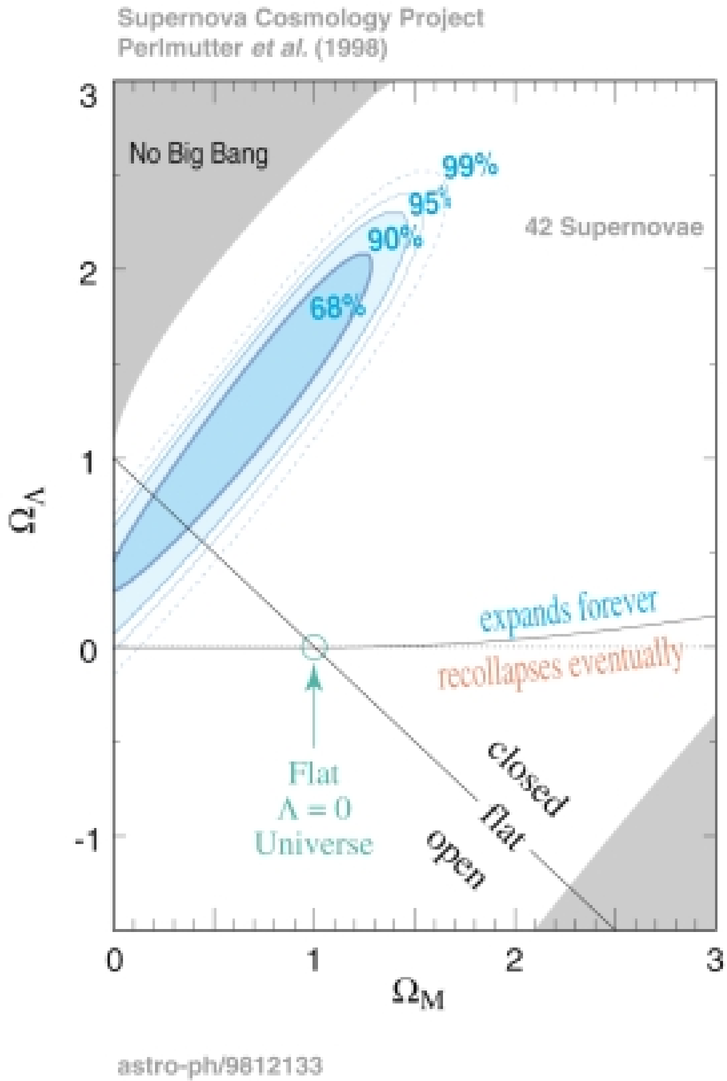
Flight Operations Review



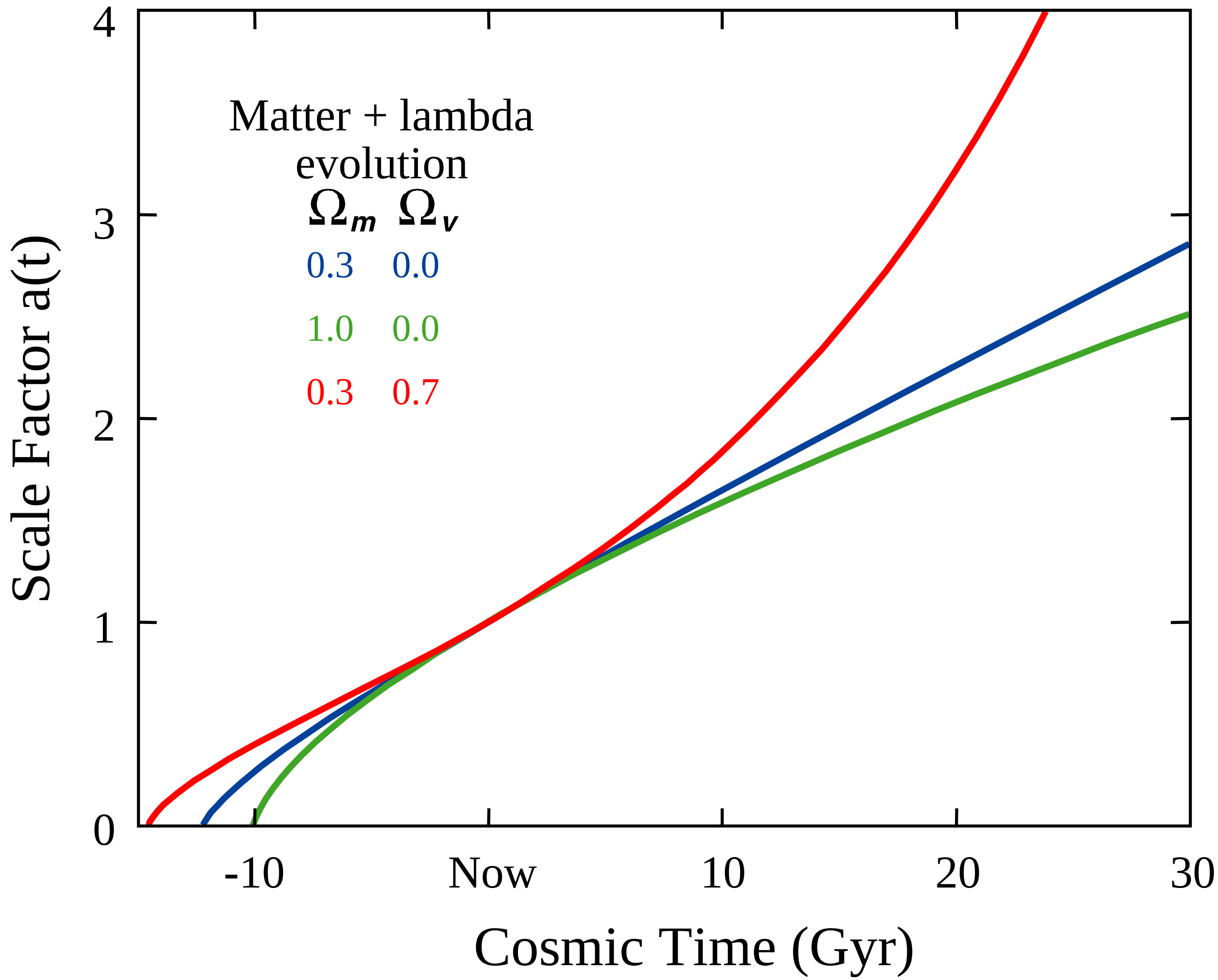
MAP990183

astro-ph/9812133

Supernovae Cosmology



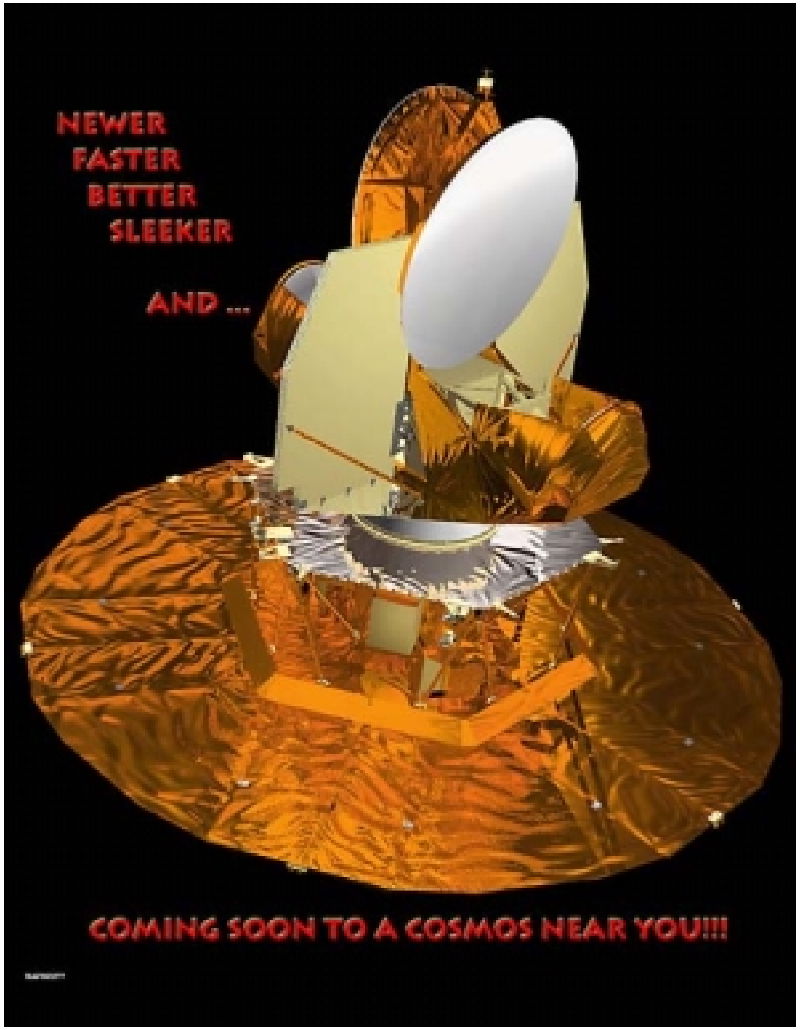
The Accelerating Universe




Big Bang Theory,
You've Got To Be Kidding.
-God
LAMAR

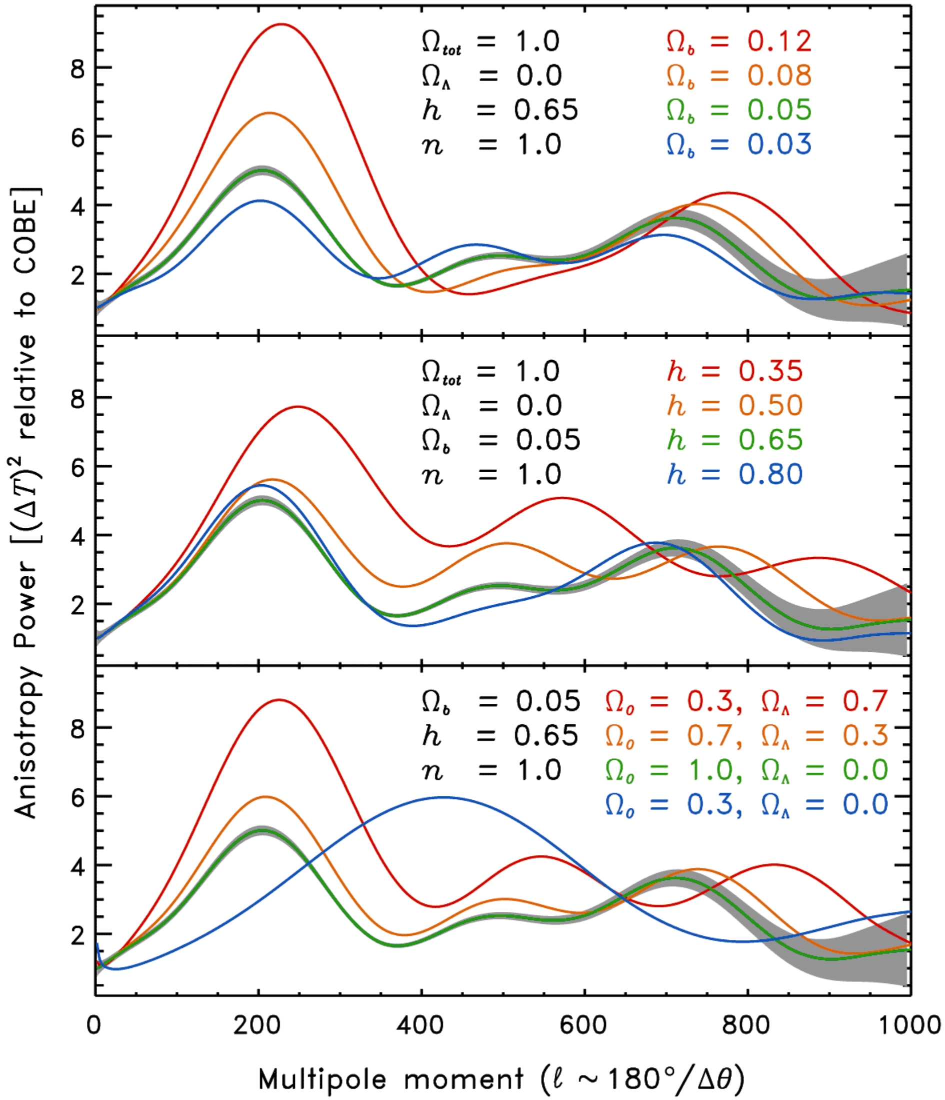
MAP

Flight Operations Review



CMB Anisotropy Power Spectra

Dependence on Cosmological Parameters



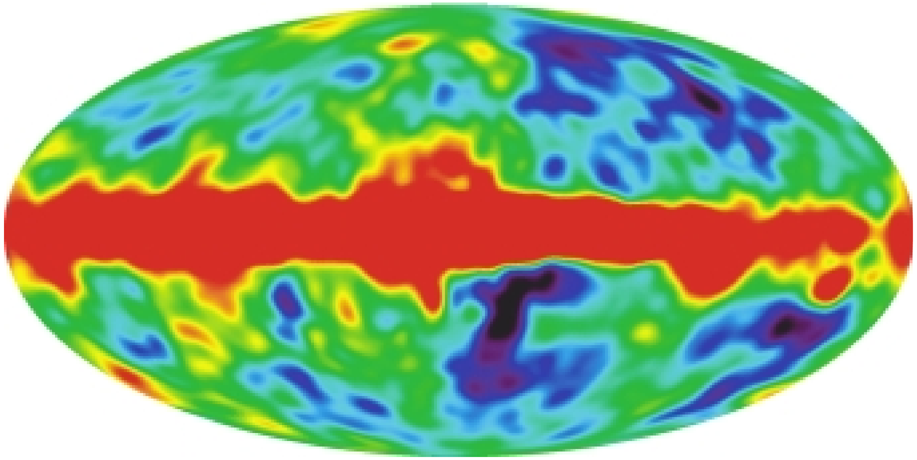
MAP990057

Nominal Science Mission

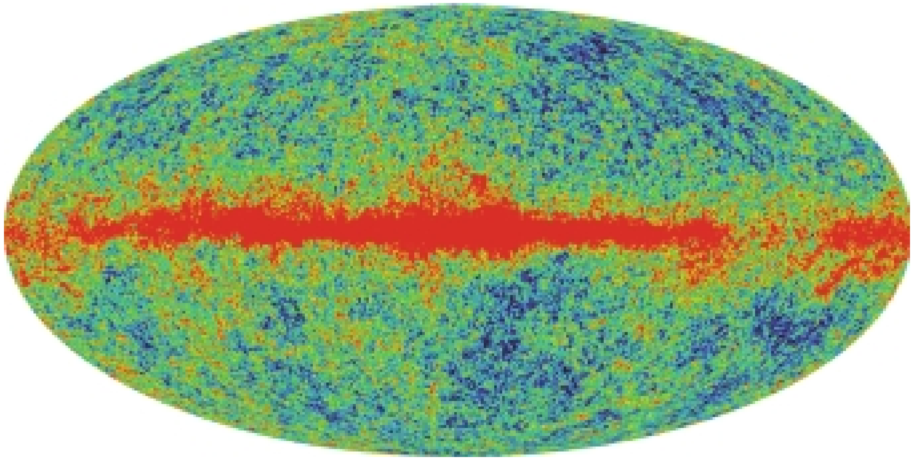
- A map of cosmic microwave background temperature
  - > 95% sky coverage–angular resolution < 0.3°
  - polarization sensitive
- RMS sensitivity of 20 μK for 0.3°x 0.3° pixels
- RMS systematic errors < 4.5 μK
- RMS calibration accuracy < 1%
  - (from sky observations)

COBE-MAP Comparisons

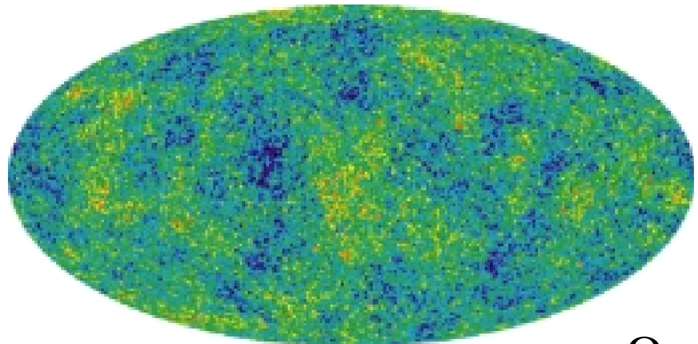
COBE DMR 4–Year Sky Map



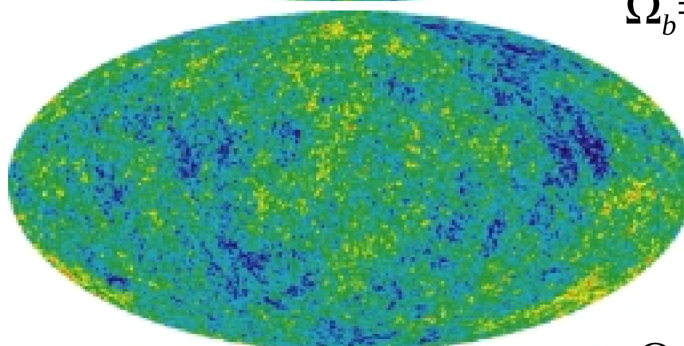
MAP Simulated Sky Map



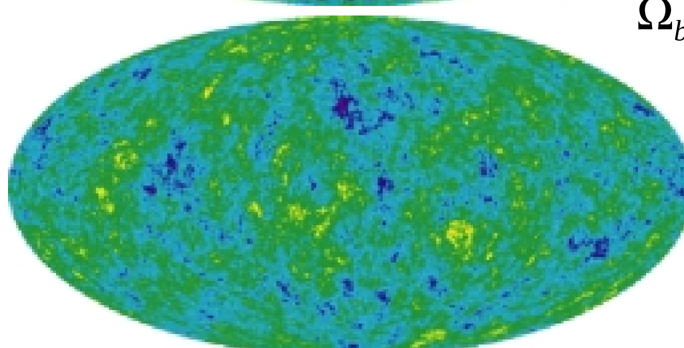
Omega Models



$\Omega_b = 0.20$



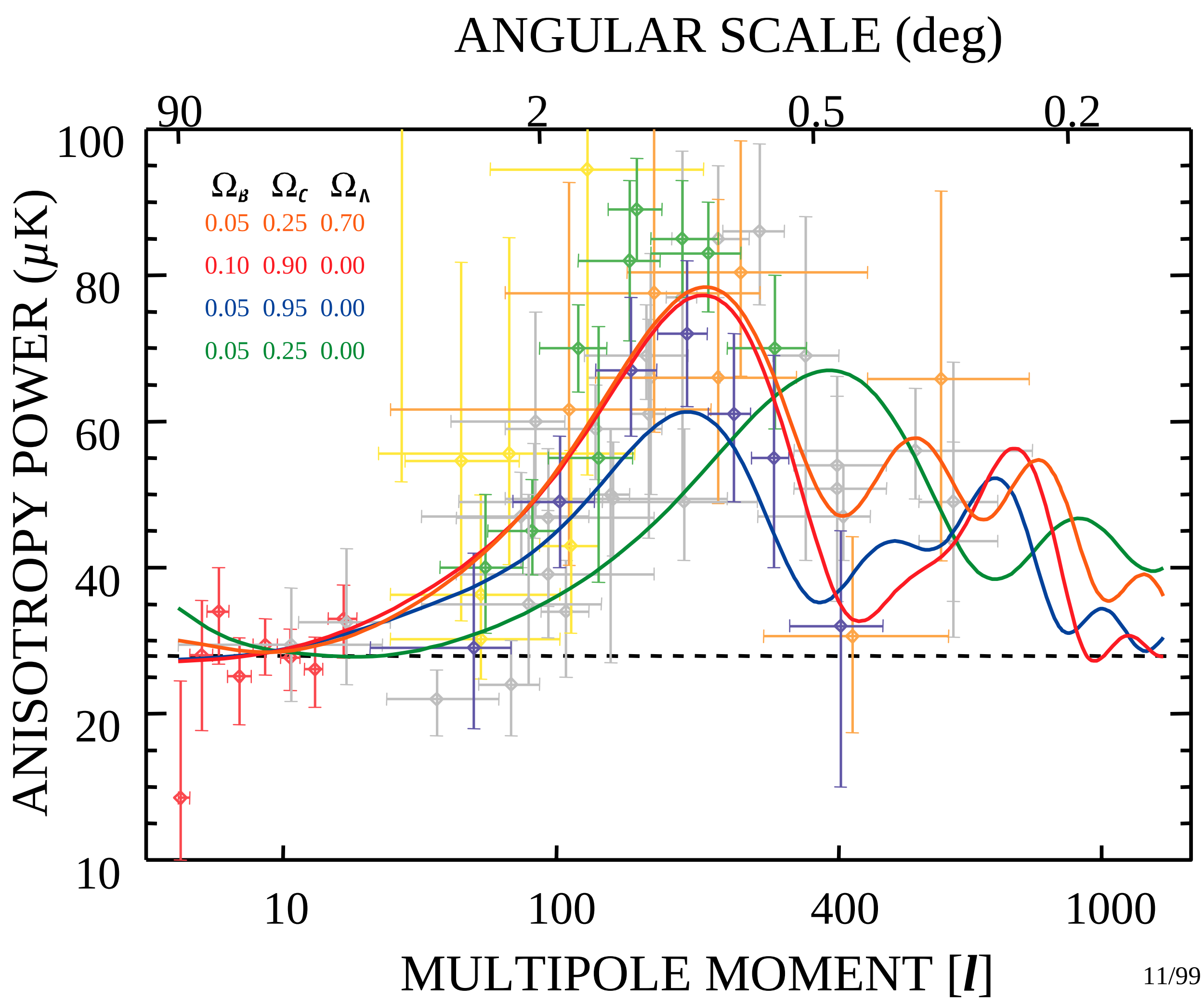
$\Omega_b = 0.05$



$\Omega_b = 0.0$

Current Anisotropy Data

Flight Operations Review

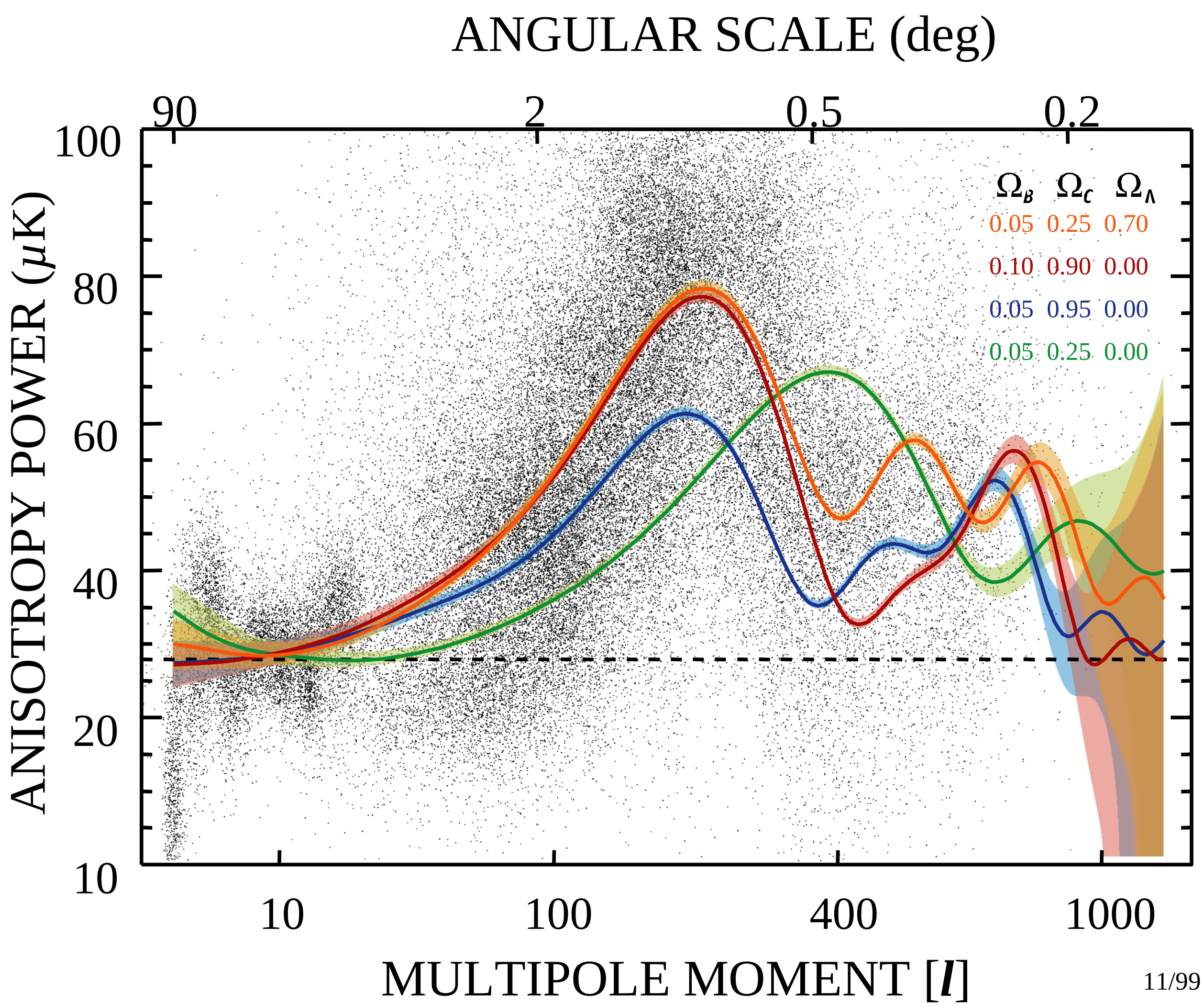


11/99

MAP990282

Current Anisotropy Data

Flight Operations Review

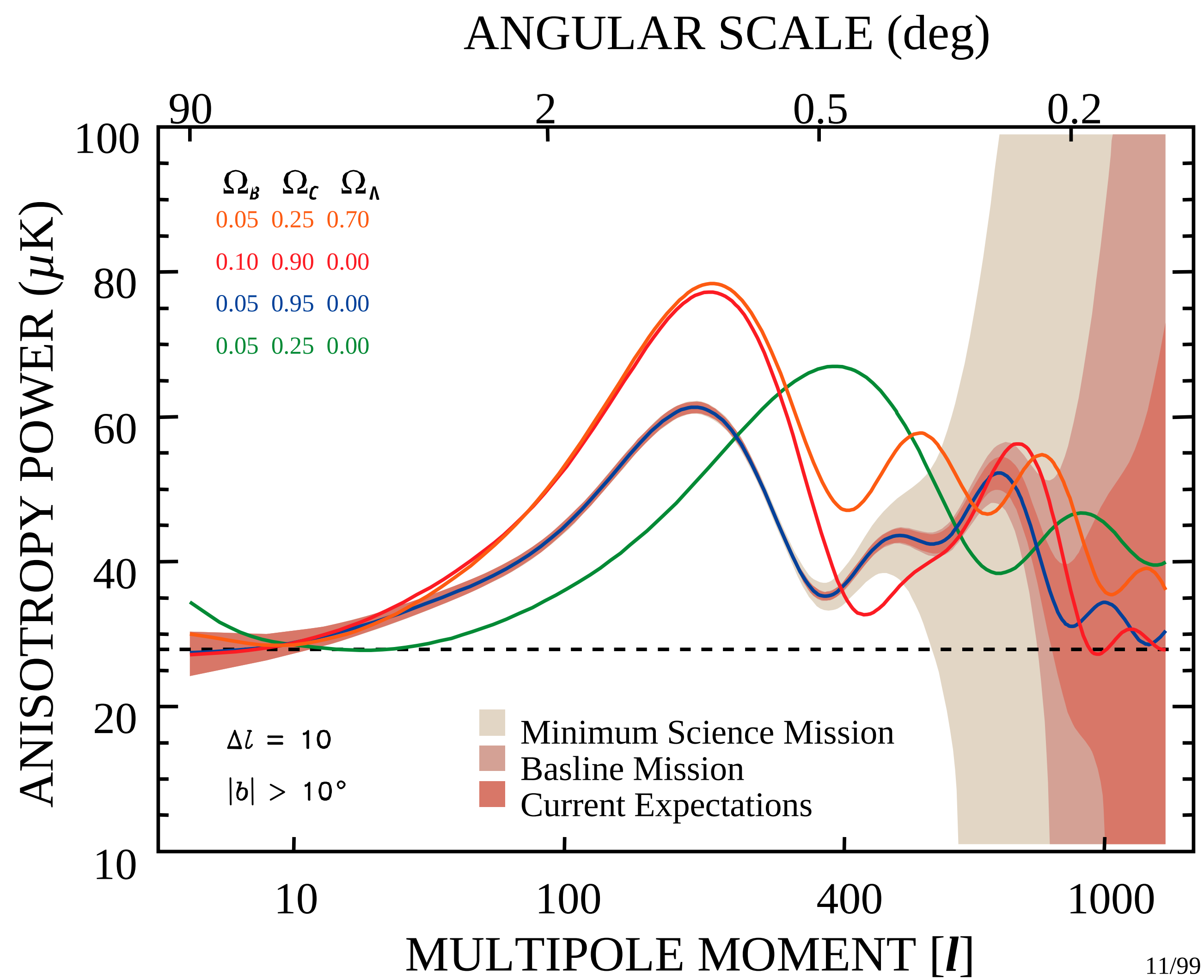


MAP990280

11/99

MAP Uncertainty Estimates

Flight Operations Review

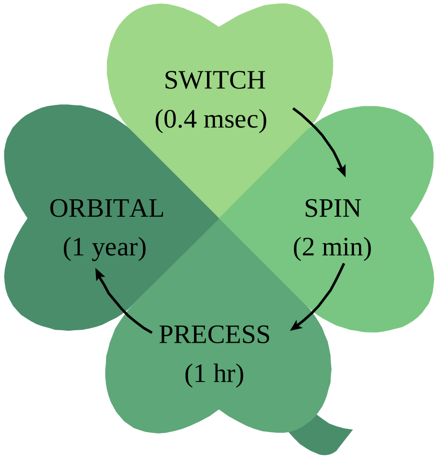


Minimization of Systematic Errors

SPIN-SYNCHRONOUS NON-SKY SIGNALS ARE THE LEADING CONCERN FOR THE PART-IN-A-MILLION COSMIC MEASUREMENT

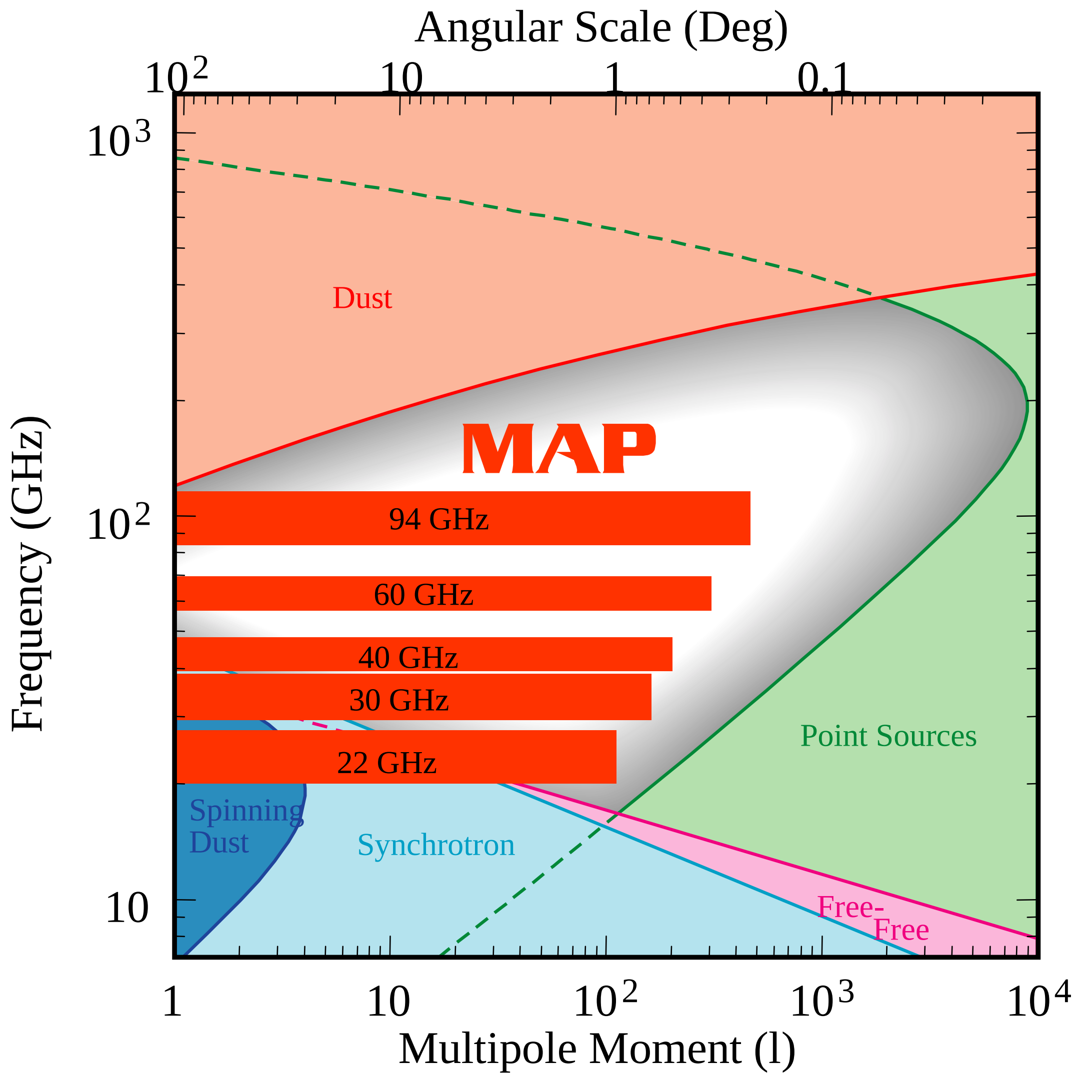
- Minimize sensitivity of experiment to non-sky signals
  - Minimize all observatory changes
    - L2 orbit; constant survey mode operations
    - minimize transmitter time; use make up heater
  - Symmetric, rapidly switched, differential radiometers
  - Rapid sky scanning (30% of sky per hour)

- Multiple modulation periods to isolate & identify systematic effects
- Distinguish cosmic from non-cosmic sky signals
  - 5 frequencies to model and remove galactic signals
  - Minimize stray diffracted signals from Earth, Sun, Moon
    - large edge taper; diffraction shielding
    - L2 orbit



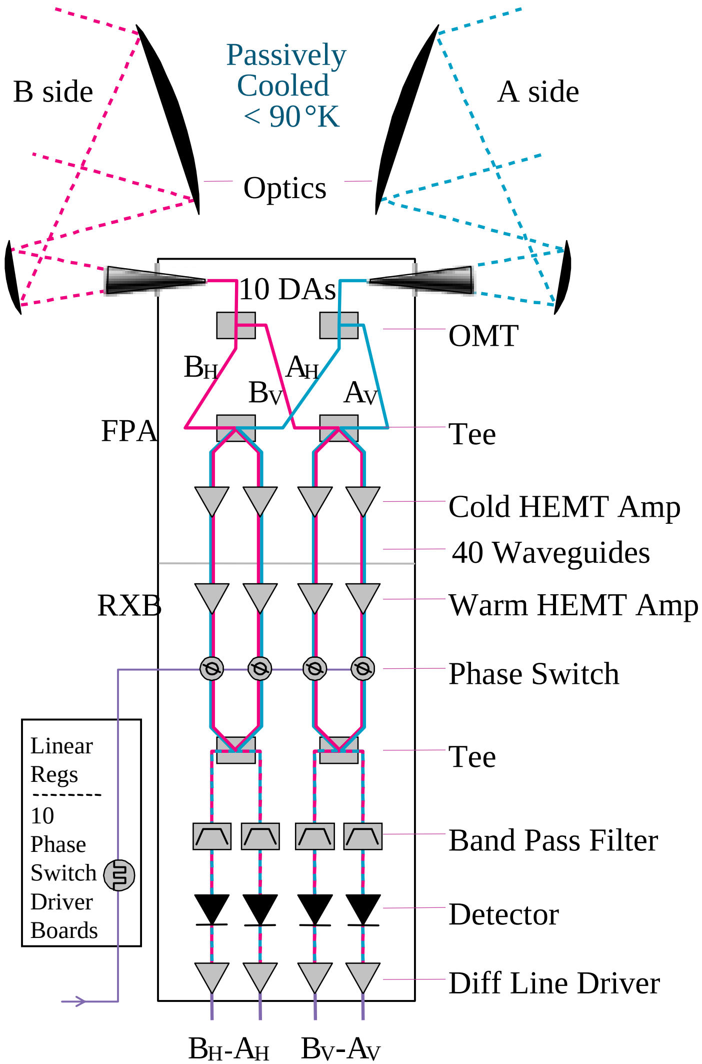
Ideal CMBR Observing Window

Flight Operations Review



MAP990039

Differential Pseudo-Correlation Radiometer



MAP990033a

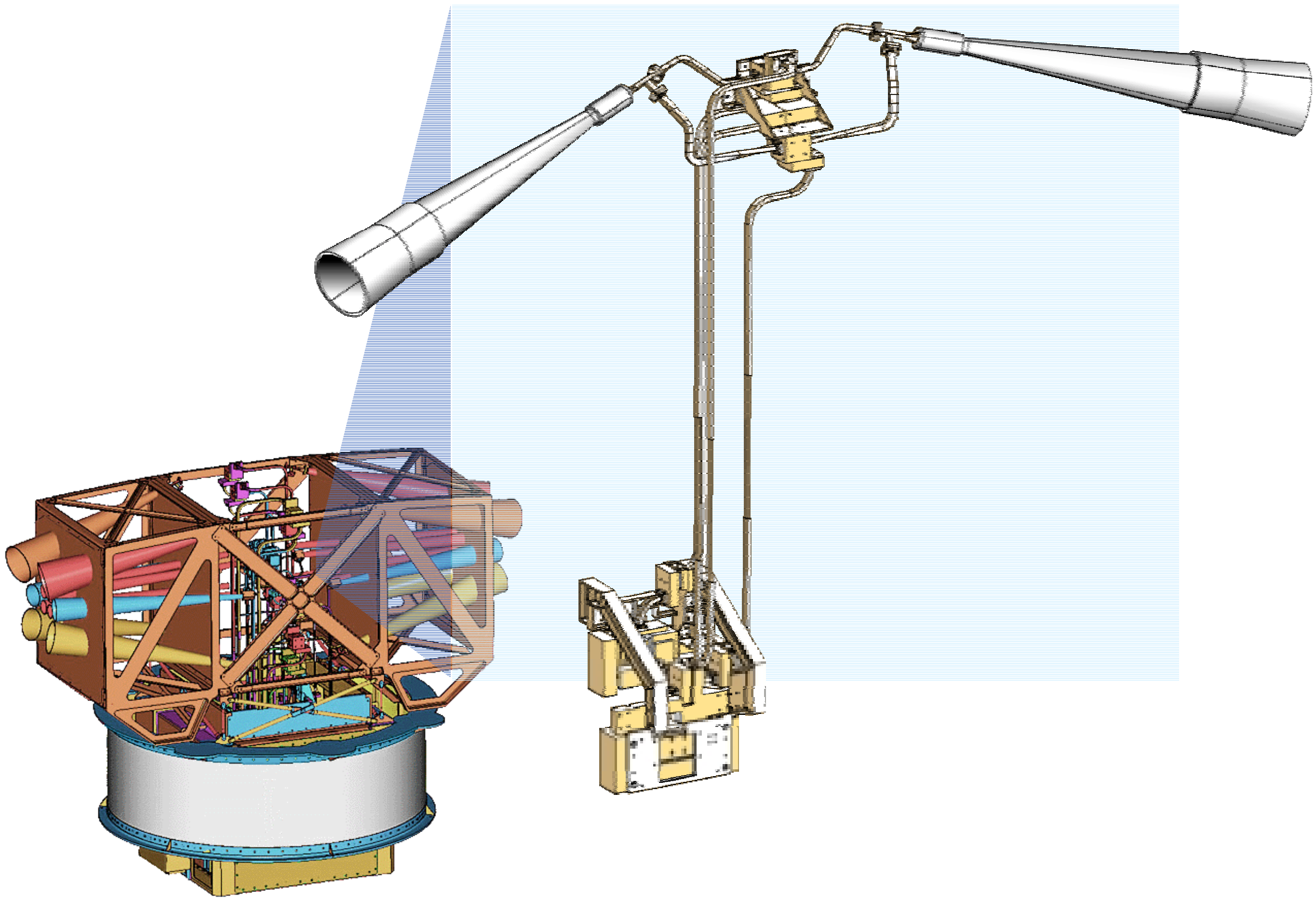
Advantages:

Symmetric differential measurements:
less sensitive to most systematic errors

Pseudo-correlation system:
gain fluctuations rejected

Rapid phase switching:
interchange of A and B signals
rejects systematics

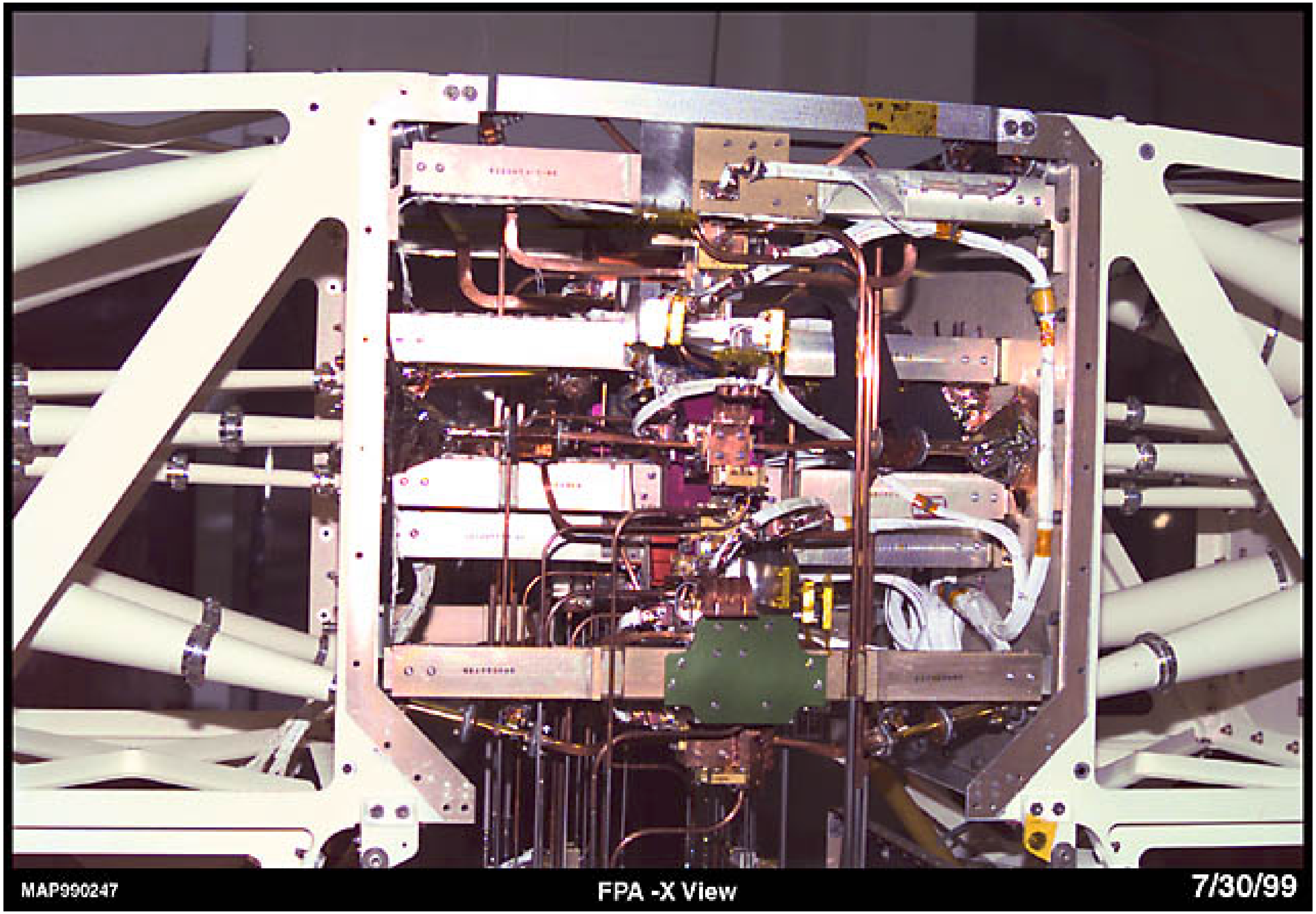
MAP Microwave System



MAP990180

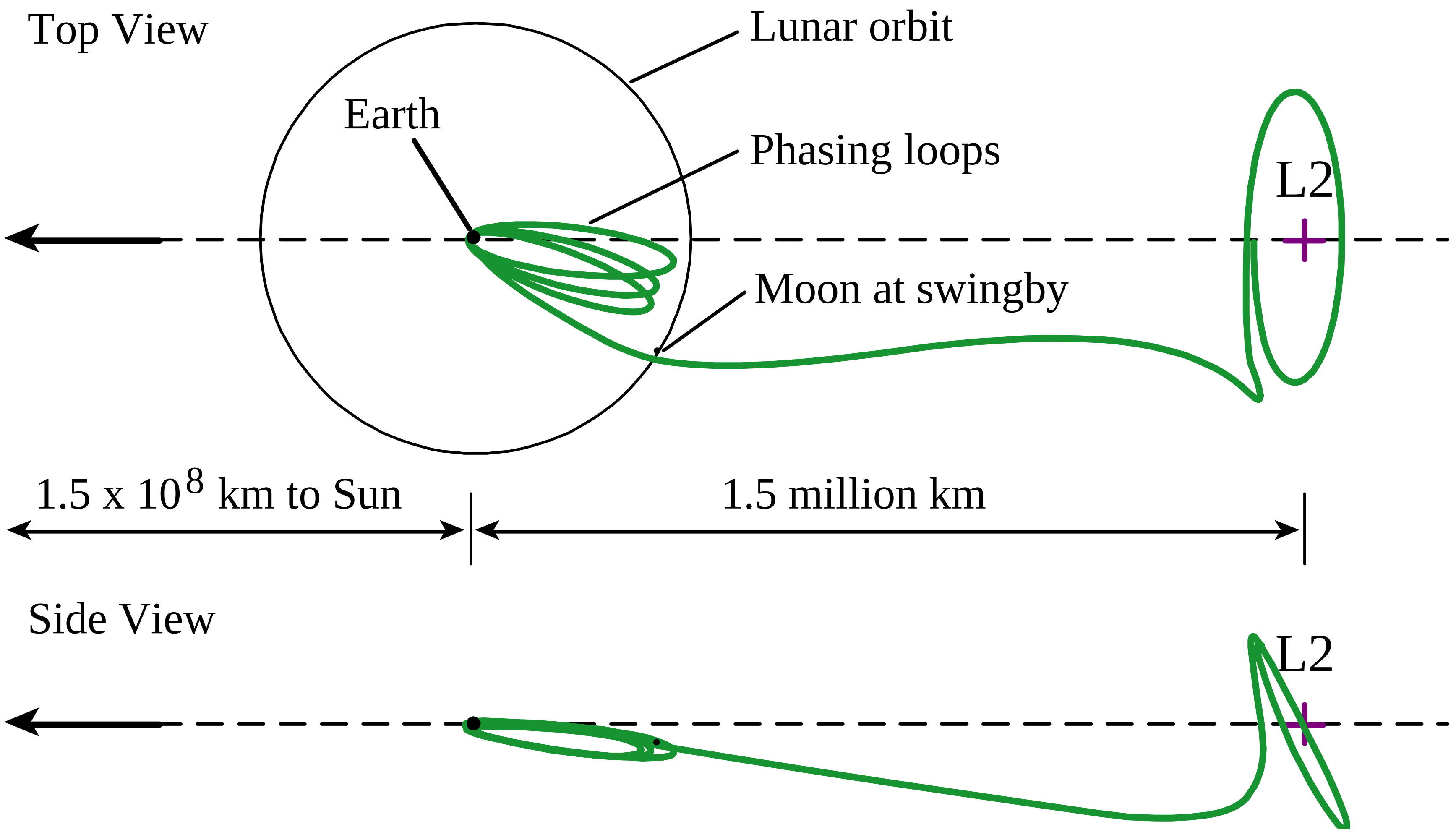
MAP FPA

Flight Operations Review



MAP Trajectory to L2

Flight Operations Review

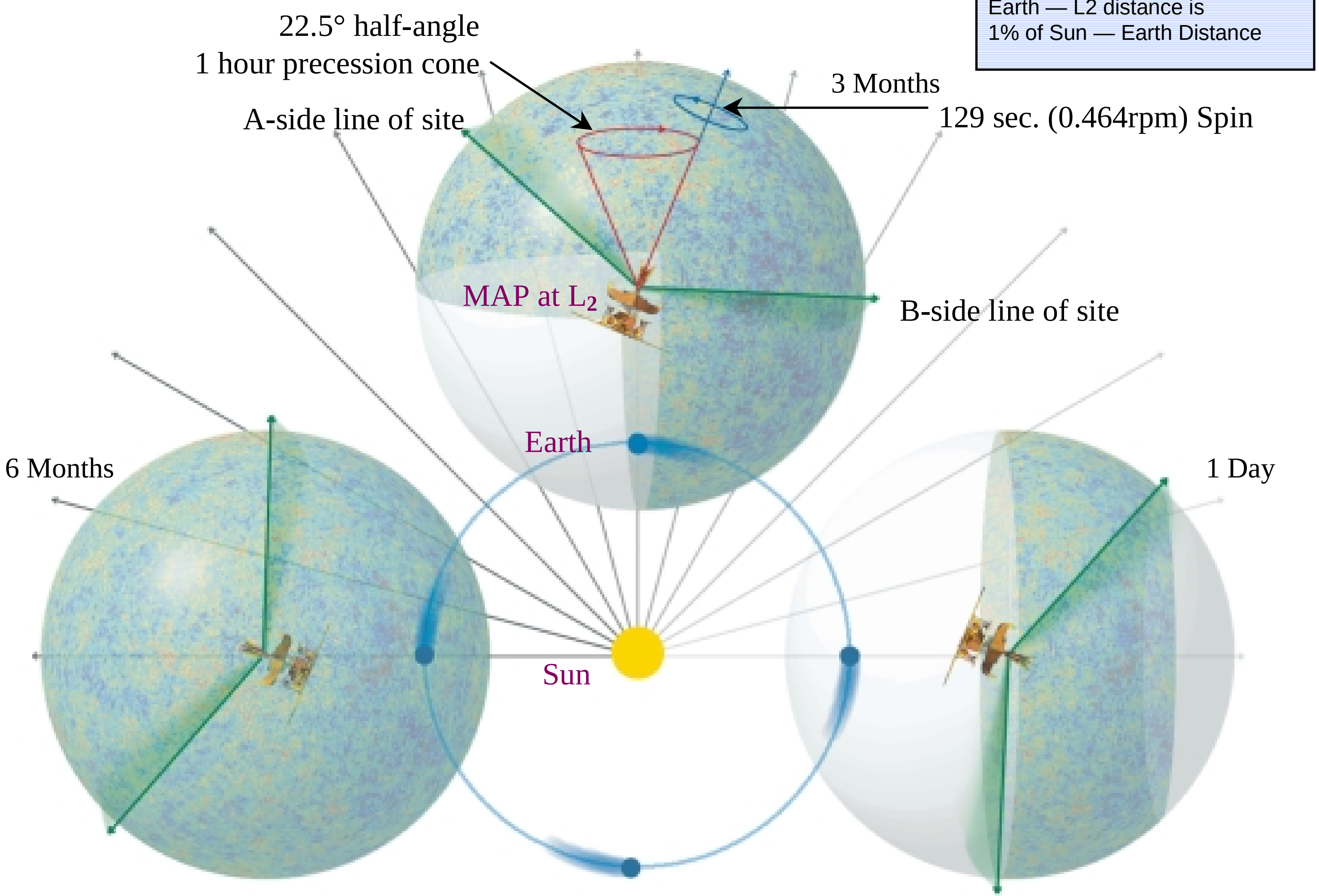


MAP990029

Sky Coverage

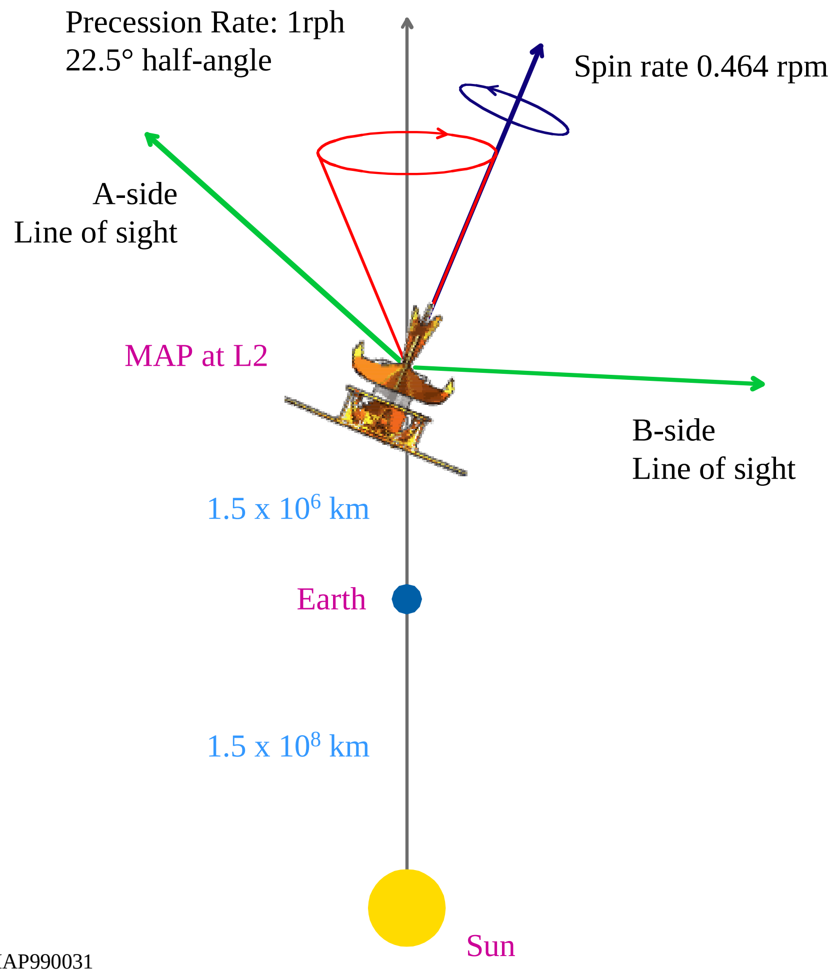
Flight Operations Review

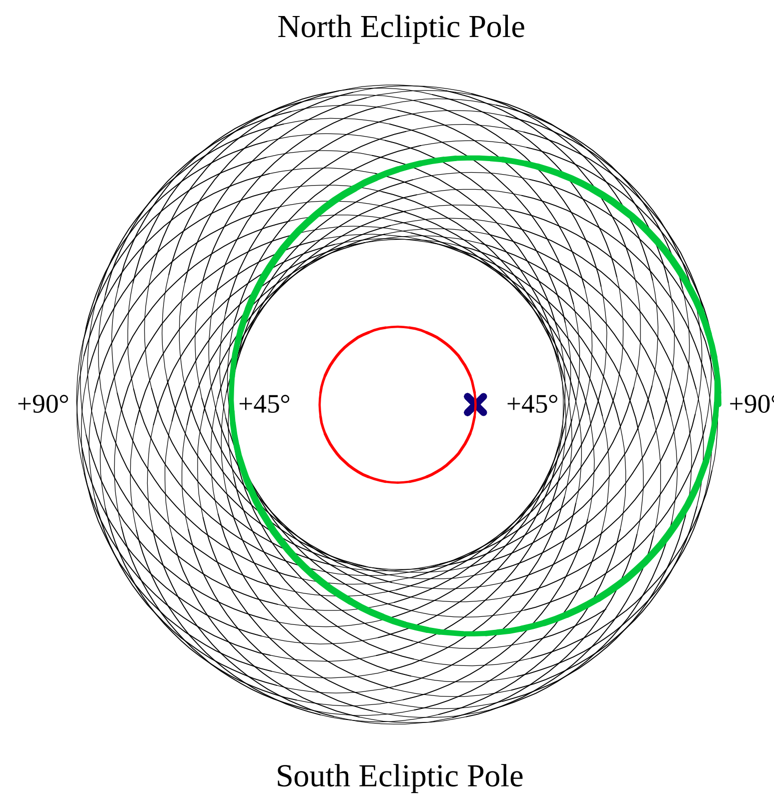
- **6 Months for full sky coverage**



MAP990159

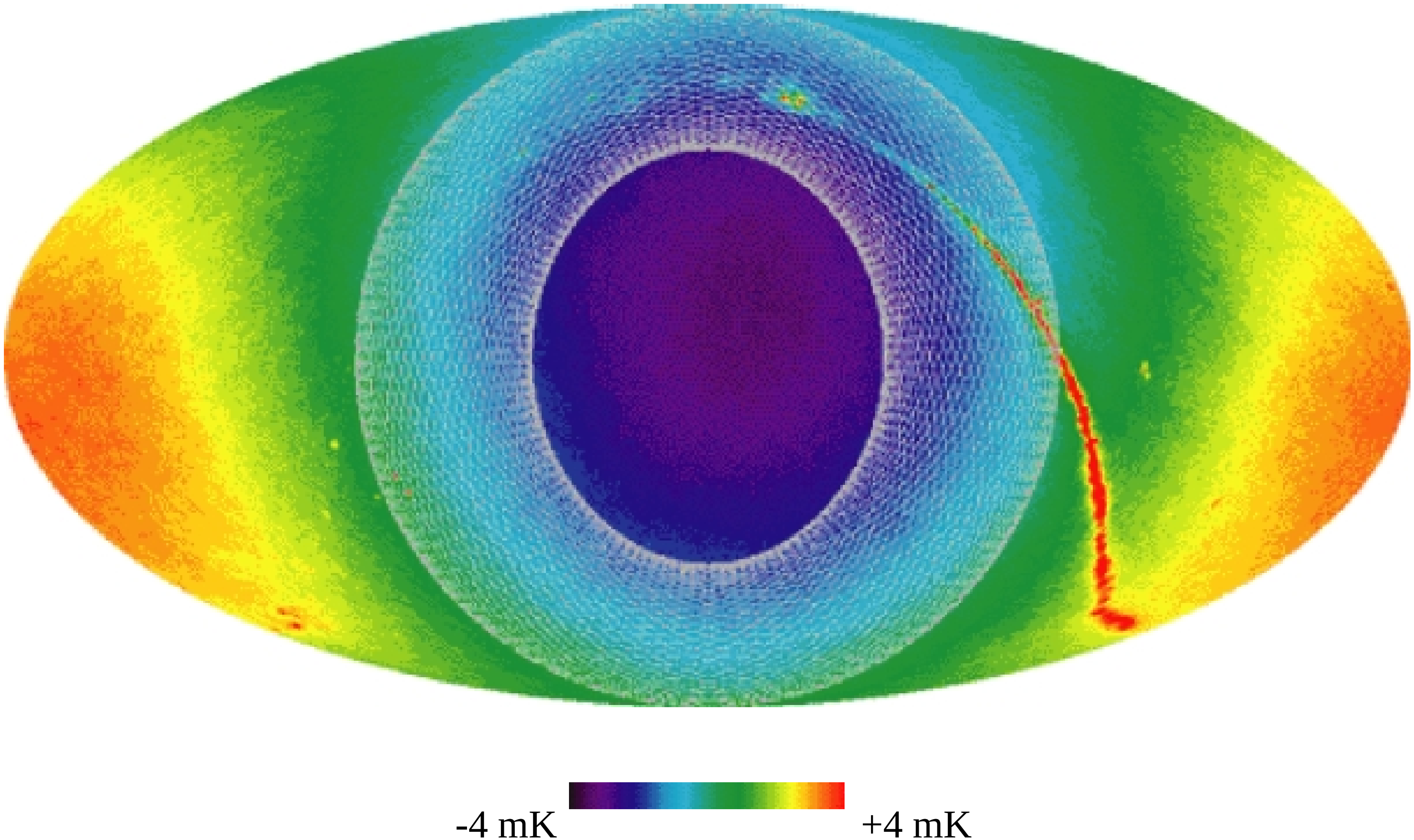
Spin Precession and Sky Coverage





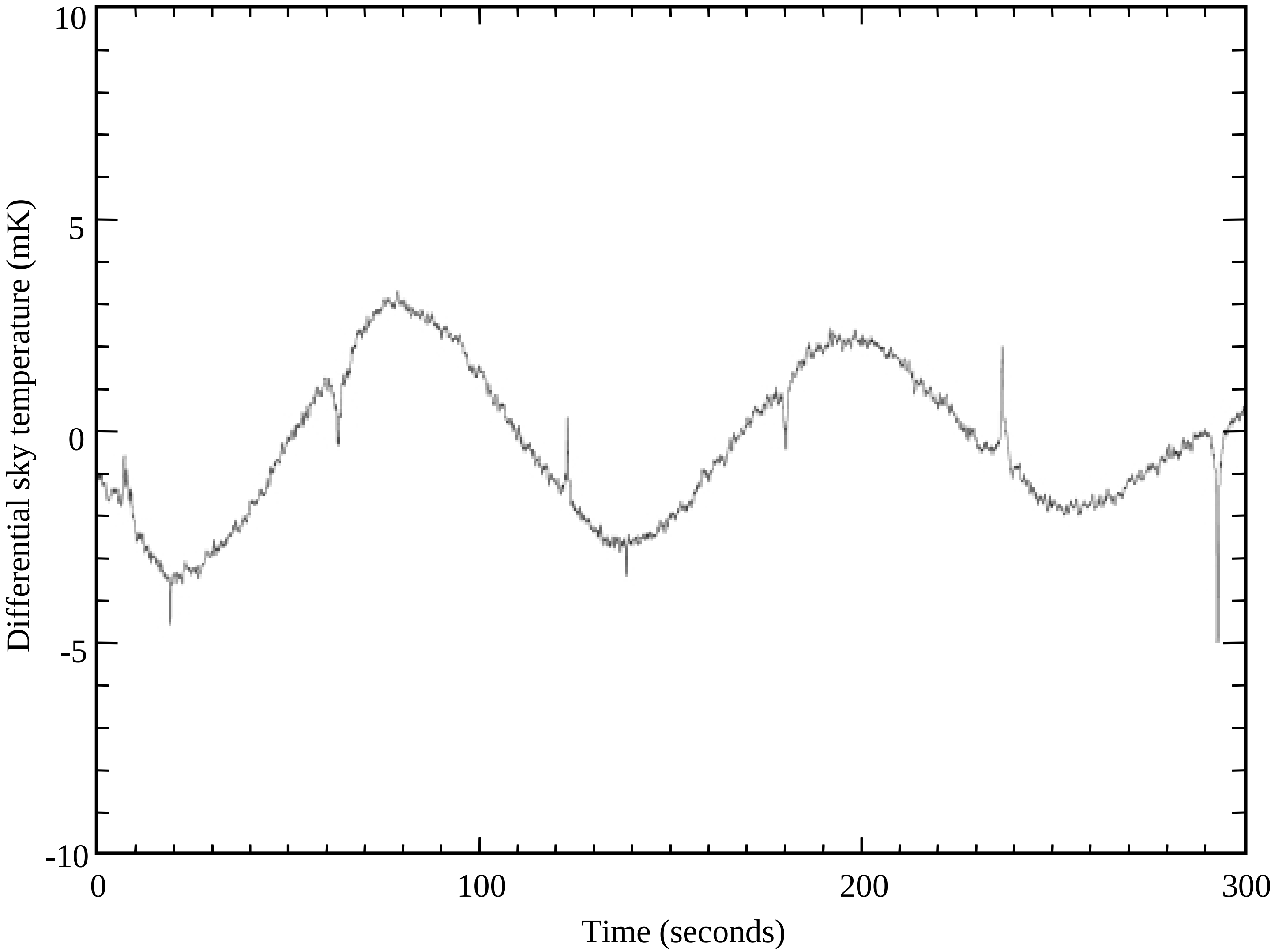
MAP Sky Coverage: 1 Hour

Flight Operations Review



MAP990107

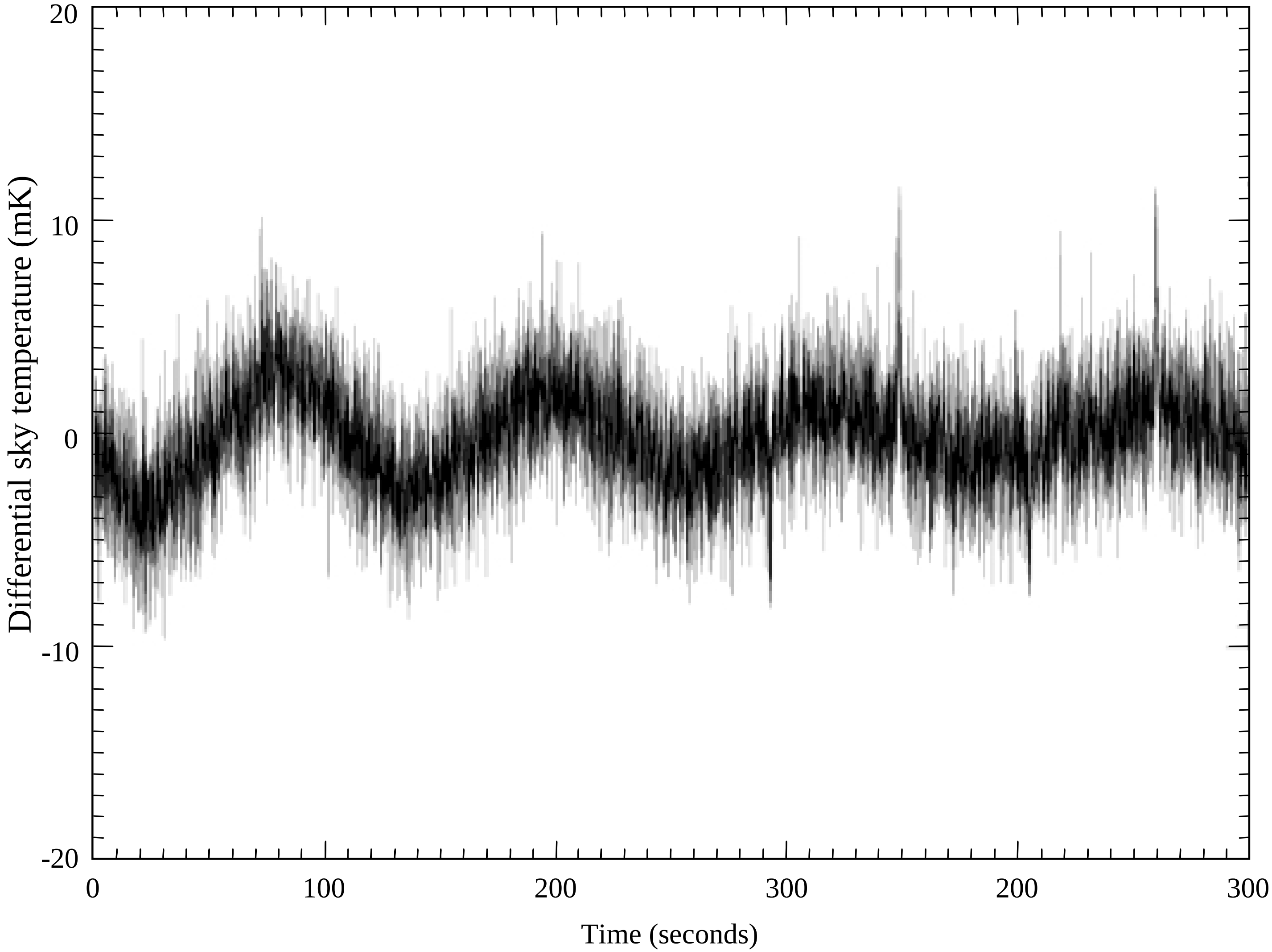
Simulated time-ordered MAP data



MAP990097

Simulated time-ordered MAP data

Flight Operations Review



MAP990099

High Quality Measurements

Quality Space CMB Mission Features	MAP
Full Sky Map	✓
True Map (Pixel Information Uncorrelated By The Instrument)	✓
Symmetric & Differential Observations	✓
Multiple Signal Modulations On Diverse Time Scales	✓
Rapid Large-Sky-Area Scanning	✓
Fully Developed Systematic Error Budget	✓
Very Low Sidelobe Beam Patterns	✓
No Atmospheric Contamination	✓
Extreme Thermal Stability With No Active Controls	✓
Self-Calibrating	✓
Minimize Microwave Down-Link Transmitter "On" Time	✓
Multiple Channels	✓
Multiple Frequencies Near CMB-to-Galactic Signal Spectral Maximum	✓

Significant Science

Over 300 scientific papers have been written in the past 4 years predicting what MAP may see...

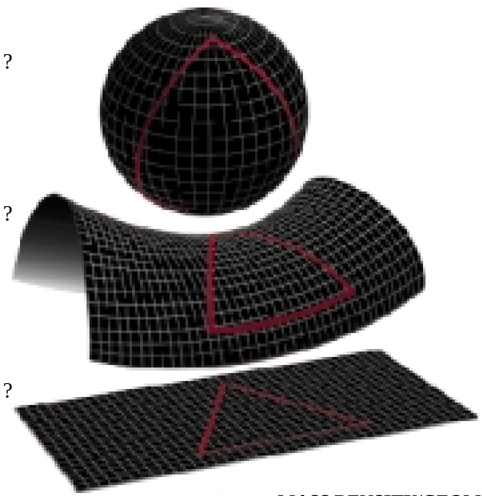
"It is not often that debates over the finer points of cosmology are played out in the pages of the daily newspapers... how to reconcile the earliest moments of the big bang with the other end of time: the eventual fate of the universe. " "If the universe is open... there will be a distinct pattern of fluctuations on the microwave sky. NASA's Microwave Anisotropy Probe... is designed to look for exactly these kinds of patterns. "

Science,279,1455 (6 March 1998)

Close Geometry ?

Open Geometry ?

Flat Geometry ?



MASS DENSITY/GEOMETRY OF THE UNIVERSE

"MAP Should be at its vantage point by 2001. Then the microwave background and the key parameters of the universe should start coming in focus. "

Science, 272,1434 (7 June 1996)

National Academy of Sciences report to NASA:

"At the top of the list for the next 10 Years or so... is refining a map of the microwave background radiation. Eagerly awaited... nudging NASA to keep a planned satellite called the Microwave Anisotropy Probe (MAP) on track... "

Science, 276, 346 (18 April 1997)

"The biggest questions about the beginning and the end of time and space could be laid to rest forever. "

Discover (19 Oct 1996)

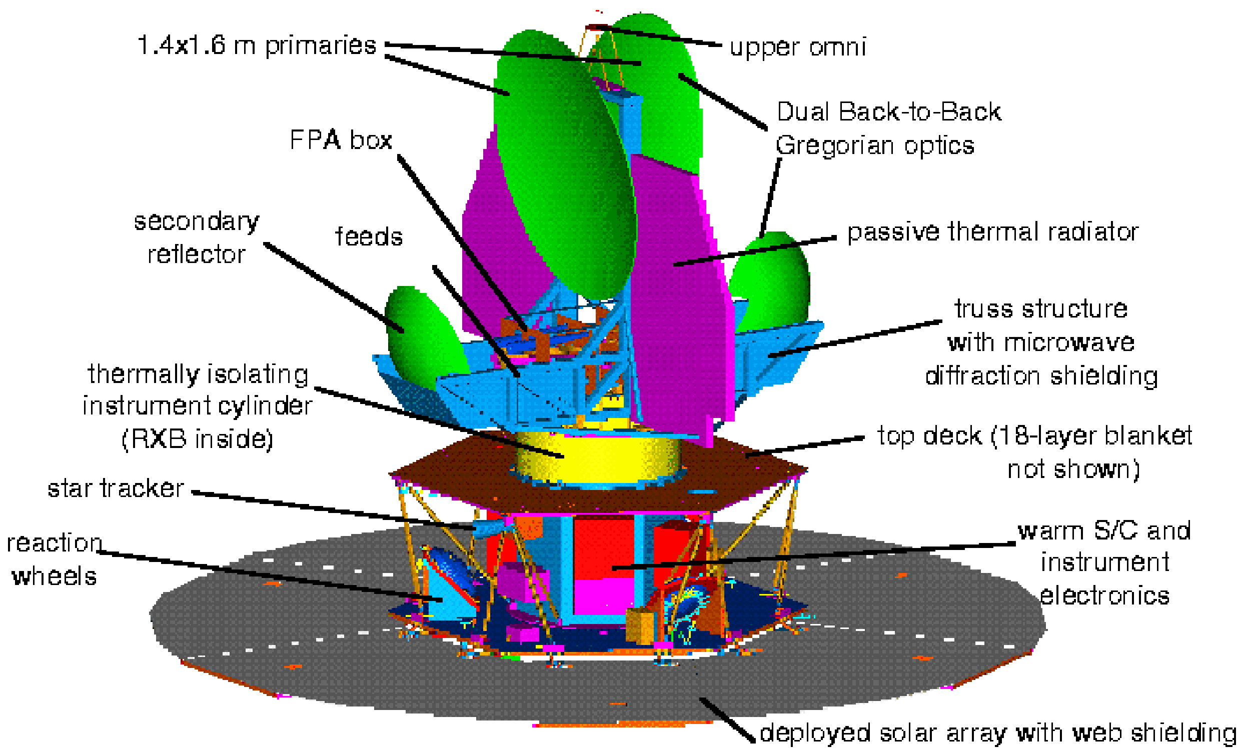
Mission Overview

- The Observatory
- Getting to L2
- Observing
- Requirements

Systems Team:

Cliff Jackson	Lisa Bartusek (Electrical)
Mike Bay	George Shiblie (Electrical)
John Ruffa (CPT/Verification)	Nancy Stafford (I&T/LV)
Joe Bolek (Verification)	Tom Ajluni (LV)

The Observatory



Observatory Description

Observatory
- Mass: 831 kg (wet)
- Power: 400W EOL
- Comm: S-band downlink @ 666 Kbps; uplink @ 2 Kbps

Science Mode Pointing
- Zero-momentum COBE-type control
- Spin rate: 2.78 °/s
- Precession rate: 0.1 °/s
- Pitch offset: 22.5° +/- 0.25°

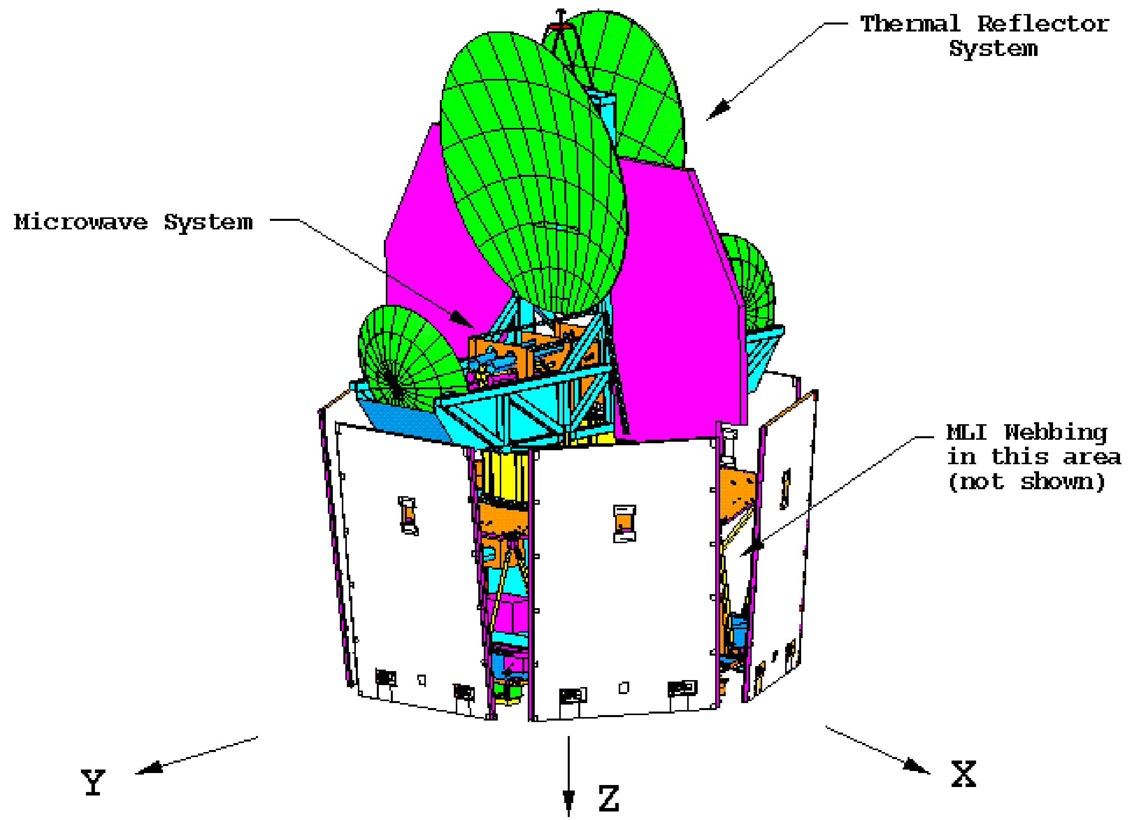
Architecture
- Mongoose V processor, 1773 data bus
- Redundant C&DH and ACE and selected components

Instrument
- Passively cooled differential microwave radiometers
- Multiple frequencies of ~22-90 GHz
- Dual back-to-back optical systems

Sensor/Actuator Complement
- 2 Star Trackers
- 2 Two-axis Inertial Reference Units
- 1 Two-head Digital Sun Sensor
- 12 Coarse Sun Sensors
- 3 Ithaco E-Reaction Wheels
- 8 1lb. Thrusters

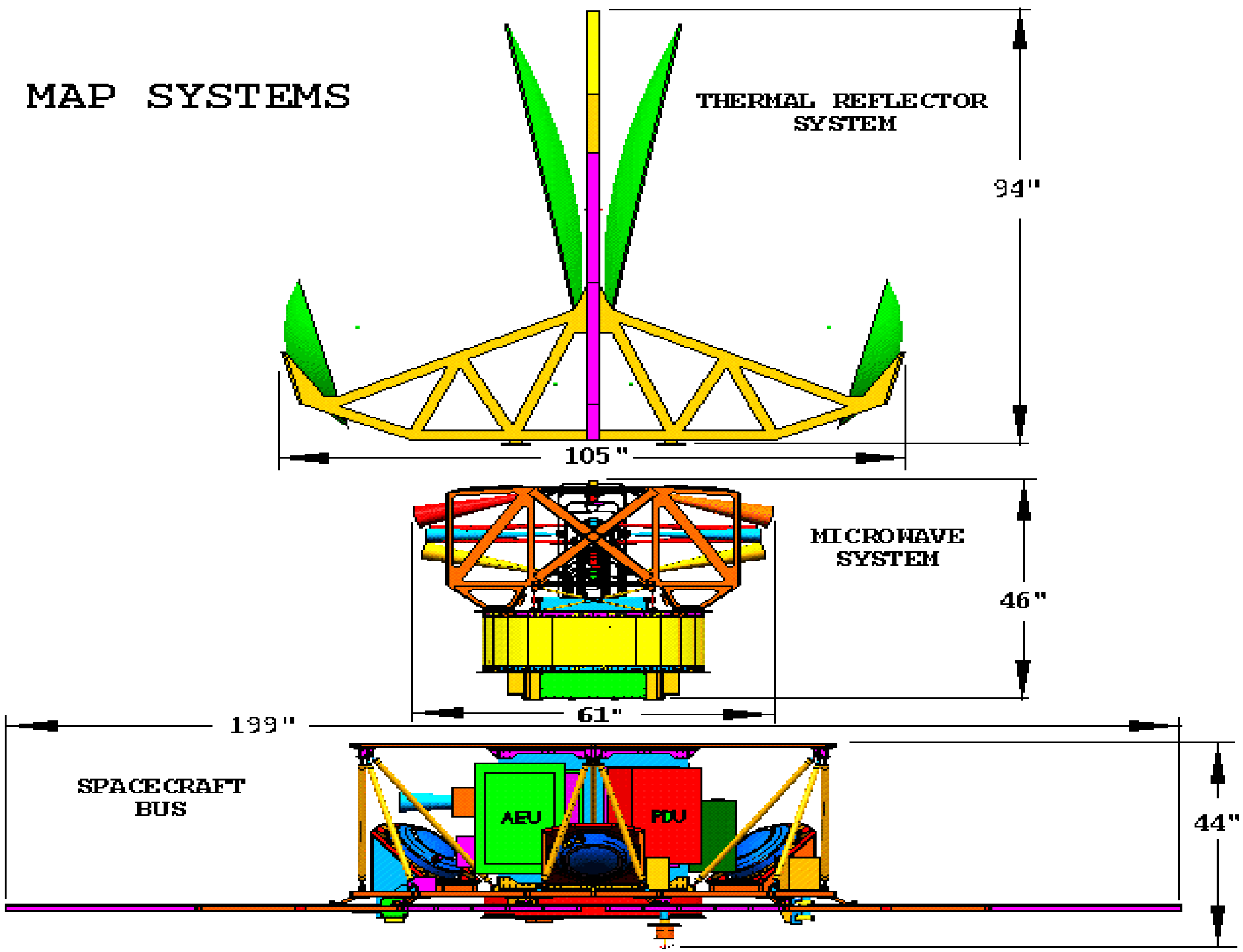
Stowed Observatory

Flight Operations Review

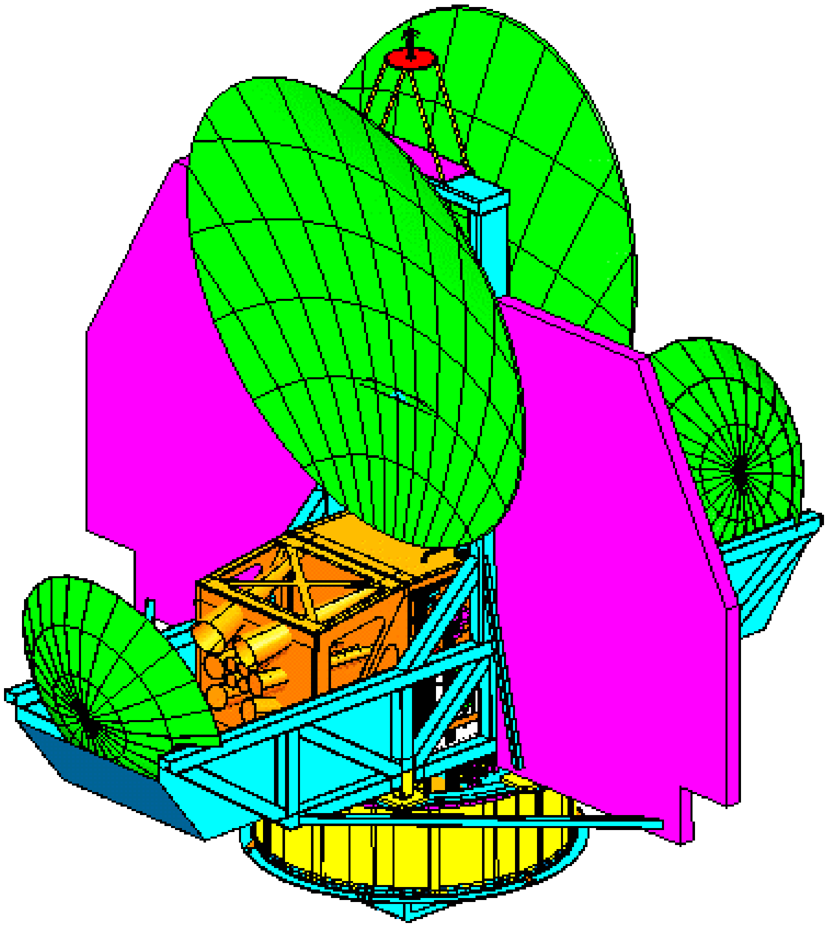


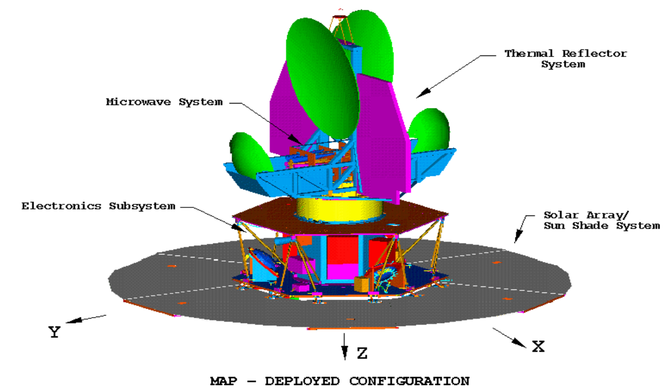
MAP – STOWED CONFIGURATION

MAP Observatory System Breakout



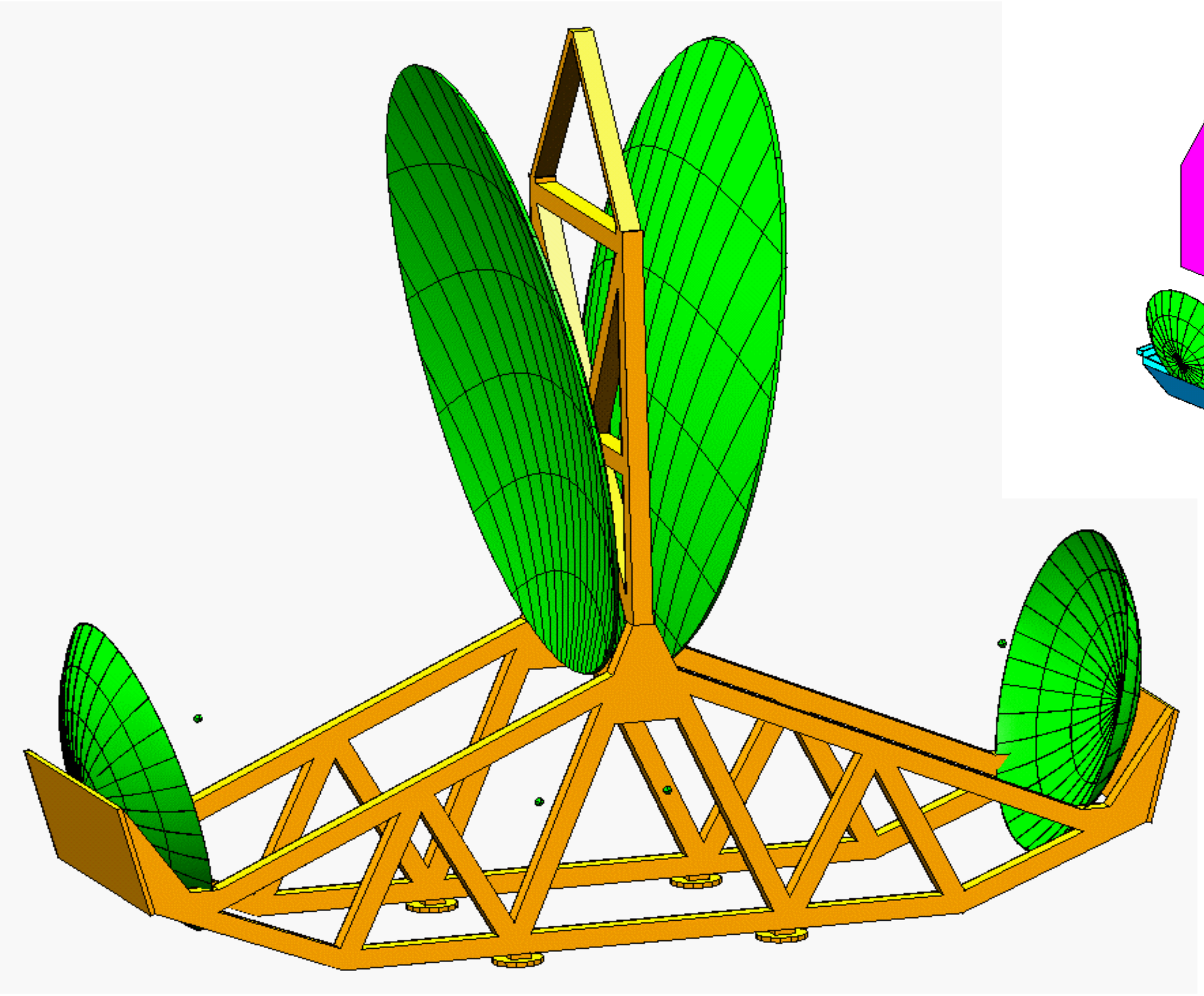
The Instrument

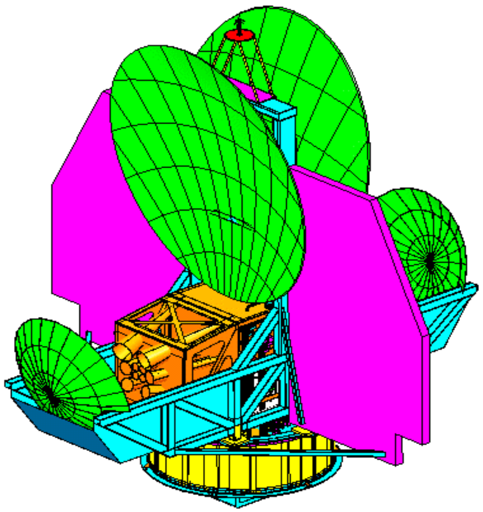




The Microwave System (MS) and the Thermal Reflector System (TRS); Instrument Electronics Boxes (AEU/DEU and PDU not shown)

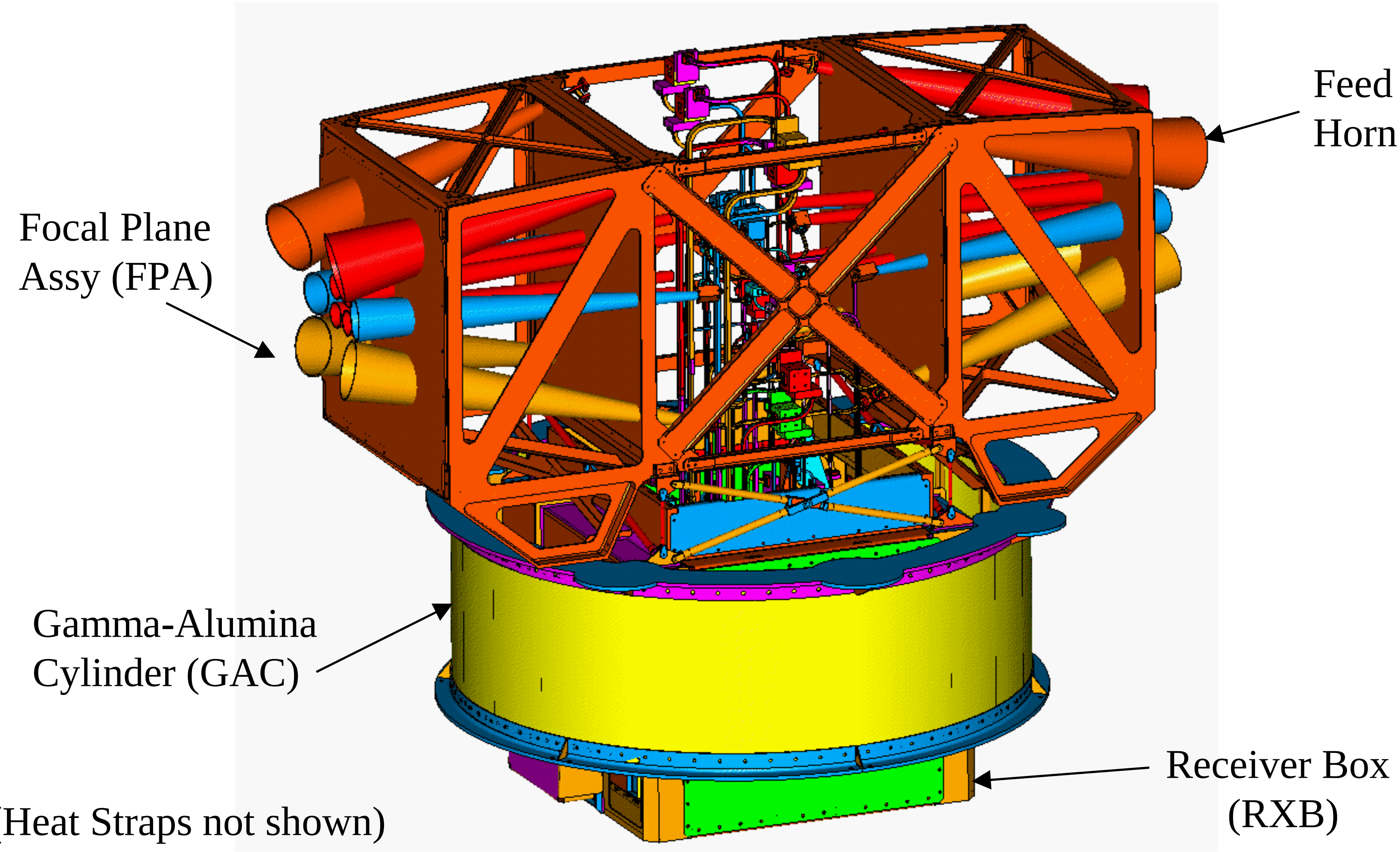
MAP Thermal Reflector System (TRS)





Primary and Secondary Reflectors on Zero CTE Graphite Truss Structure; Radiators not shown

Microwave System

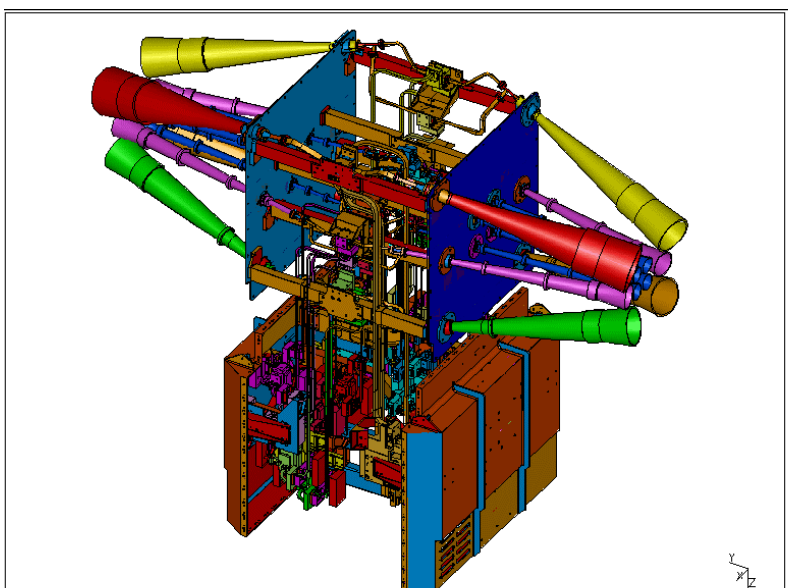


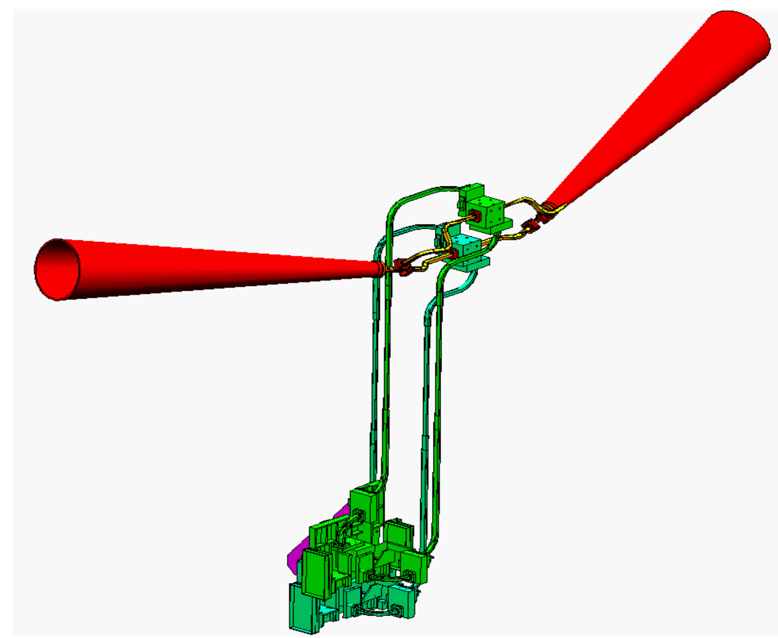
(Heat Straps not shown)

Feeds & Differencing Assemblies (DAs)

MS: Focal Plane Assembly (FPA; 95 K) and Receiver Box (RXB; ~288 K)

Differencing Assembly (1 of 10) with Feeds and cold/warm signal processing hardware





MAP Requirements Overview

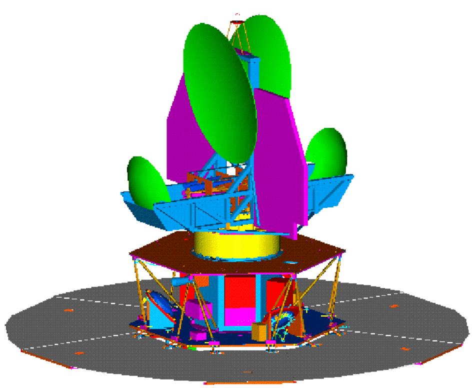
Science
- CMB map with:
- 20 uK sensitivity
- < 4.5 uK systematic errors
- 0.3º angular resolution
- Full-sky coverage
- Polarization sensitive

Mission
- 1-10 deg orbit about L2
- 27 month life (2 yrs. observing)
- Electrical System Specification
- Radiation: 27krad total dose
- Surface charging: all surfaces conductive
- Internal charging: no ungrounded conductors, harness shielded

Instrument
- Differential sensing using back-to-back Gregorian optics
- 5 frequency bands
  - 22GHz, 30GHz, 40Ghz, 60Ghz, 90GHz

Attitude Control and Propulsion
- Compound spin observing strategy
  - 2.45-2.5º/sec @ 22.5º above spin plane
- Pointing knowledge of 1.8 arcmin RMS
- Spin axis precession 22.5º +/- .25º from sun vector
- Trajectory correction, orbit maintenance, momentum unloading

Mechanical
- Shadow the instrument
- 7325 launch loads, 10 ft. fairing
- Sun-shade flatness
- Alignment and access



Thermal
- FPA HEMT's < 95K
- HEMT stability of 0.5mK p-p over spin period
- Electronics boxes 0-40C
- Inst. elect. stability of 10mK p-p over spin period
- Wet prop comp. - 10-50C

C&DH
- Real-time and stored commanding
- Real-time and stored telemetry
  - at least 30 hours on-board storage
- On-board timing resolution of 1ms
- Ground time correlation to 1s

Comm
- CCSDS uplink @ 2kbps
- CCSDS downlink
  - minimize transmission ti
- 70m DSN prime, 34m back
- 2-way tracking

Ground System
- Real-time and stored commanding
- Telemetry display
- Trending, level-0 processing
- Orbit, trajectory, and pass planning
- Data reduction and analysis (map making)
- Data archiving

Power
- 400W EOL
- Energy storage to support initial sun acquisition and safemode entry
- Bus stability

Operations Drivers

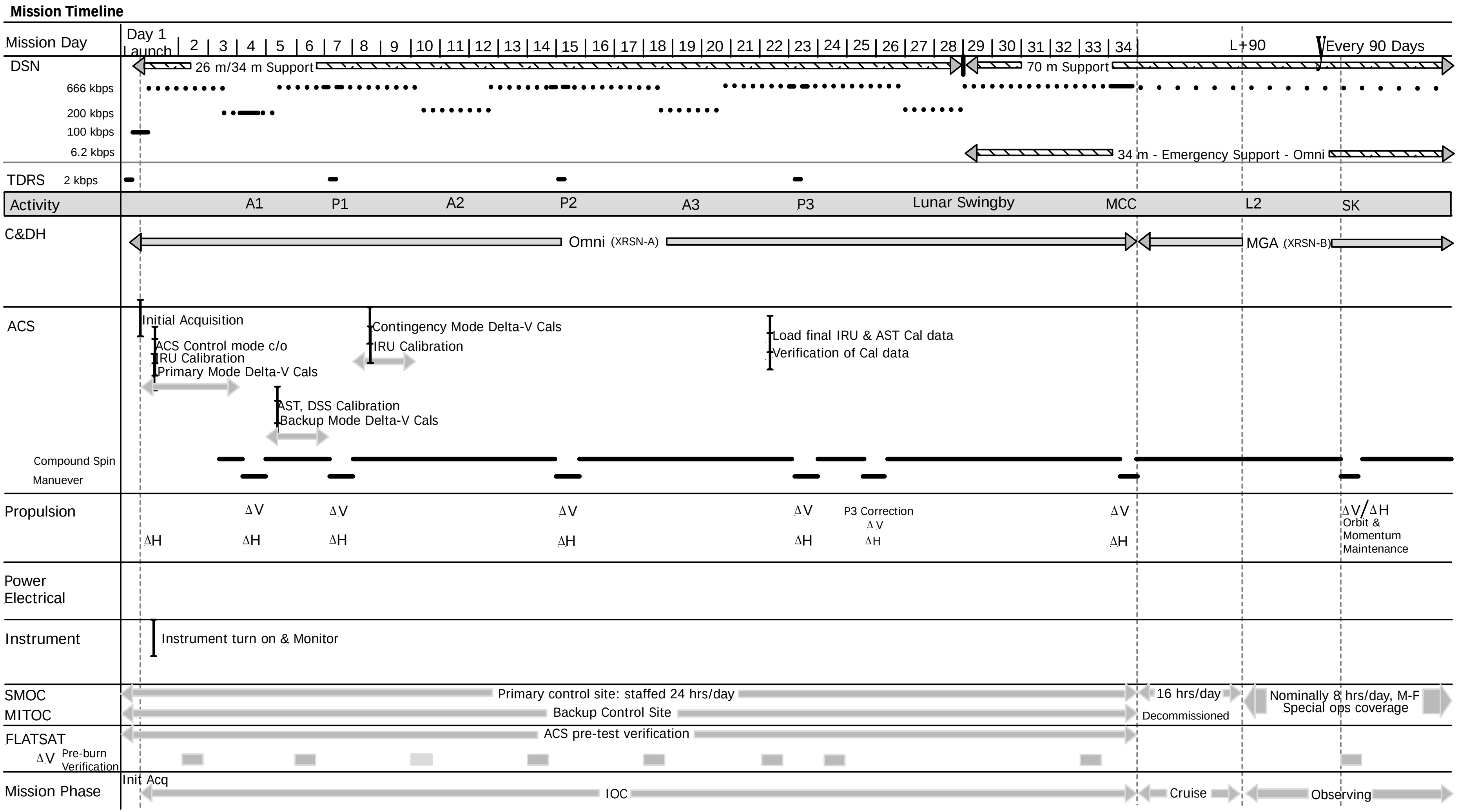
- Observatory Thermal/Electrical Stability
  - L2 orbit
  - Minimize maneuvers (4 times/year)
  - Attitude constraints on maneuvers during instrument cool-down period and at L2
  - Quiet observatory--not much should be happening during observing
- RF isolation
  - Minimize transmitter on time
  - 70m DSN downlink required
- Small fuel tank
  - Complicated trajectory with lunar gravity assist

Mission Overview

- **Launch**
  - Launched out of the ER, November 2000
  - Delta 7425/Star 48 launched into 185 x 290,000 km orbit
- **Separation and acquisiton**
  - Separation after 3rd stage burn; sun acquisition within 37 minutes
  - Monitor separation through TDRSS
- **IOC**
  - Spacecraft and instrument checkout; sensor calibration
- **Orbit**
  - Phasing loops to achieve a Lunar Gravity Assist
  - 90 day cruise and arrival into a lissajous orbit around L2
- **Normal Operations**
  - 37.5 Minute pass/day on the DSN 70 m antenna
  - Store and forward science and H/K data, PB = 666 Kbps
  - Single stored command load/wk

Mission Summary Timeline

Flight Operations Review



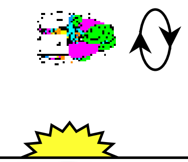
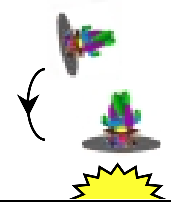
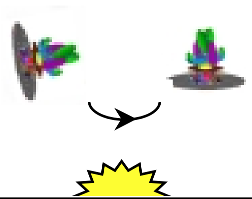
Launch Requirements

Altitude/ Orbit	185 km circular parking orbit for 3rd stage burn, Fixed C3 of -2.6 +/-11.7 m/s based on 831 Kg spacecraft for 185 x 290,000 km orbit
Inclination	28.75°
RAAN and Argument of Perigee	Set for 3rd stage burn Latitude and Longitude at the point that “aims” the semi major axis at the moon where it will be during the lunar encounter
Launch Window	One opportunity/day for ~10 days each lunar month
Coast Attitude	Control Coast Attitude for Sun normal to solar array at slow 1.0 °/sec roll
Sep Attitude	Set by third stage burn attitude
Sep Rates	0 +/-2 RPM along spin axis, 0 +/-2 °/sec transverse tip off rate
Communications	TDRSS Command and Telemetry at separation, DSN coverage within within 30 minutes of separation

Launch and Ascent Events

	Go to internal power (10 minute hold capability)
	Launch
• L-5:00	MECO
• L	Fairing separation
• L+4:24	SECO 1
• L+4:50	Orient to restart burn attitude
• L+11:36	Start barbeque roll
• L+13:20	Stop barbeque roll
• L+20:10	Stage II restart and SECO-2 (4 second burn)
• L+59:30	Third-stage burn (88 seconds)
• L+63:17	Yo-yo despin
• L+64:51	Observatory separation
• L+71:01	Deploy arrays (~2 minutes)
• L+71:06	Sun Acquisition complete
• L+71:31	
• L+106:00	

Launch & Phase Loop Solar Orientations

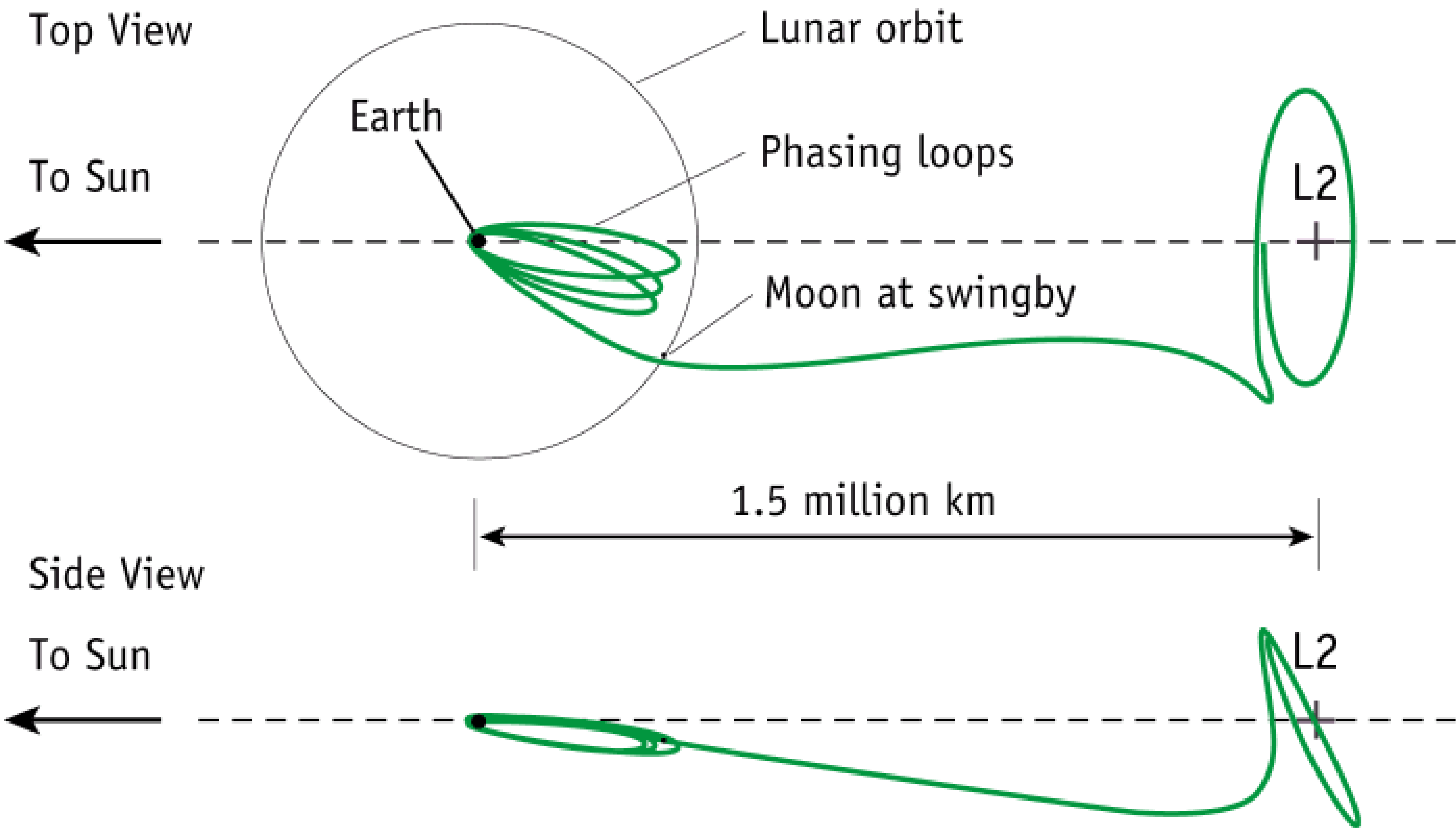
Launch through second stage burn	L + 0.0 - L + ~13.7 min.	• Fairing separation at ~5 minutes • Battery discharging	
Coast	L + 13.7 - L + ~64.5 min.	• 1.0°/sec barbecue roll • Arrays normal to sun; bat. charging • But, in eclipse ~ first 40 minutes	
Separation through Acquisition	S + 0.0 - S + ~35.0 min.	• S/C separates ~90° from sun • Solar arrays deploy	
Phasing Loops	2-4 weeks	• Nominal 22.5° attitude w/ sci-ops • In maneuvers Rx ±55° off 0° and Ry ±25° off 0°	
Cruise	~3 months	• Nominal 22.5° attitude • Acquiring science data	
Observing	>= 2 years	• Acquiring science data • Momentum unloading and station-keeping maneuvers • Nominal 22.5° attitude	

Trajectory Philosophy

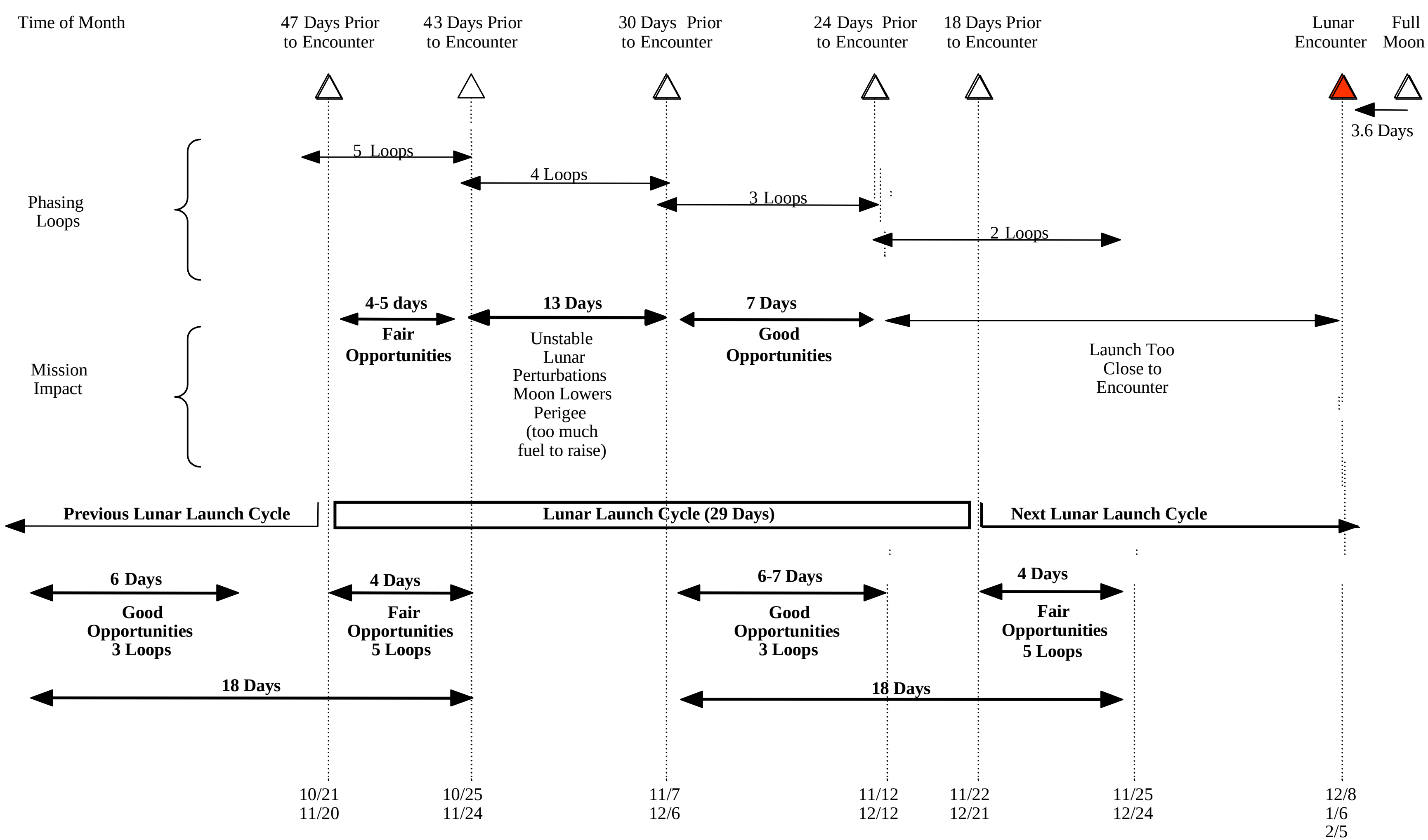
- Utilize Lunar Gravity Assist to achieve L2 Orbit
- Lunar Gravity Assist occurs approximately -3.6 days before full moon (-132° after New Moon)
- Launch Vehicle 3rd Stage Burn places MAP in a phasing loop with apogee ~70% of Lunar distance
- Select a fixed C3 of -2.6
  - maximizes Spacecraft mass into the parking orbit
  - provides ability to accommodate launch vehicle errors and multiple launch days
- Utilize phasing loops to correct Launch Vehicle insertion errors and adjust for multiple launch opportunities

MAP Trajectory to L2

Flight Operations Review

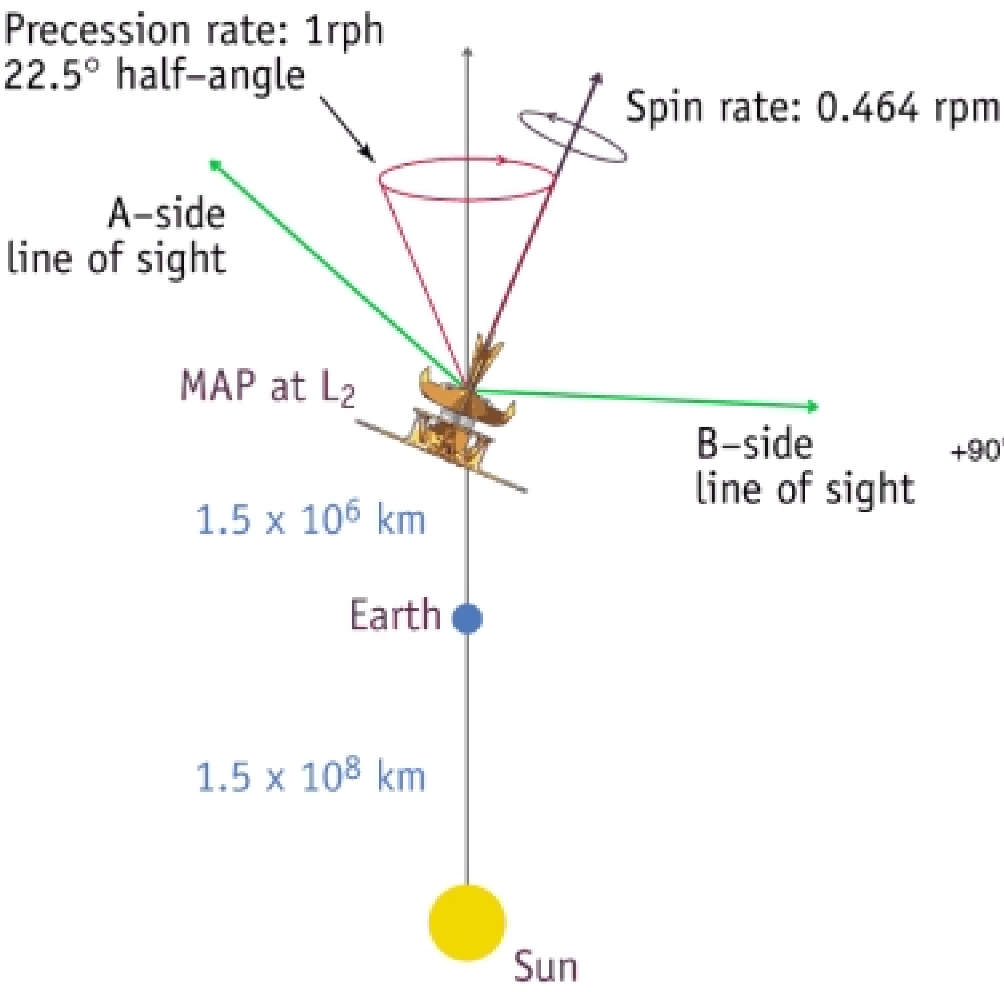


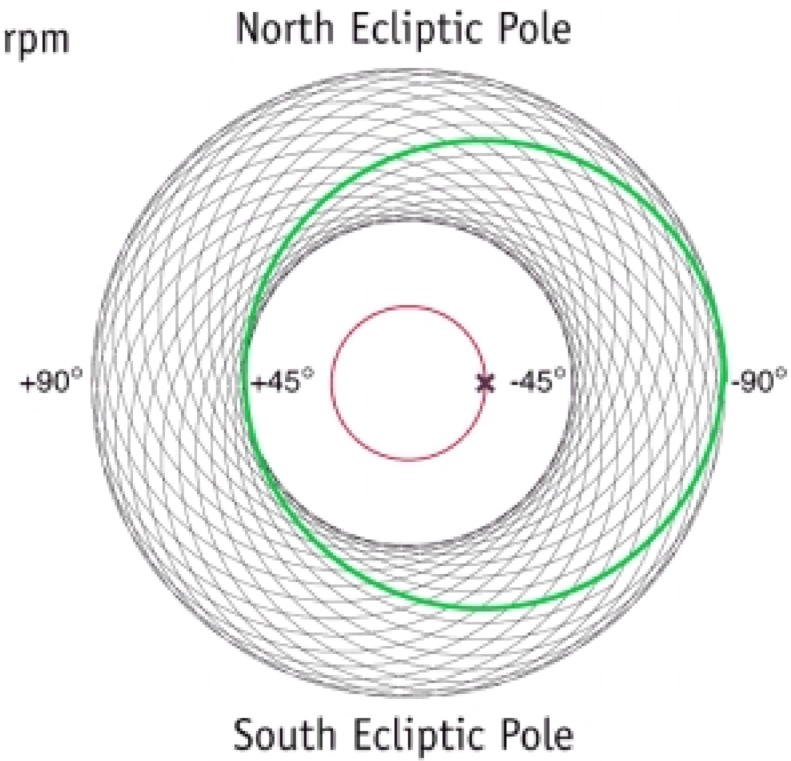
Launch Opportunities



MAP's Spin Precession and Sky Coverage

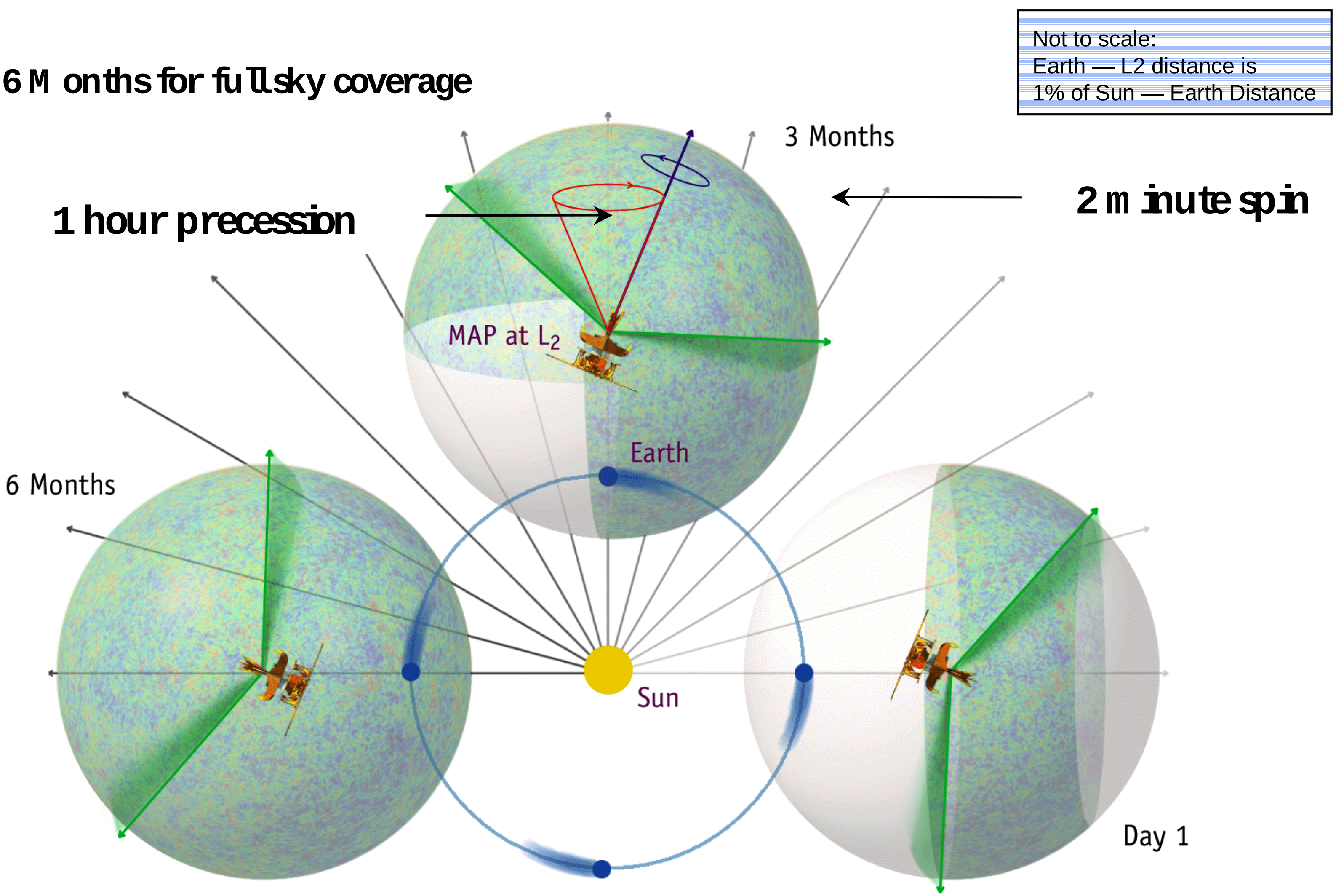
Flight Operations Review





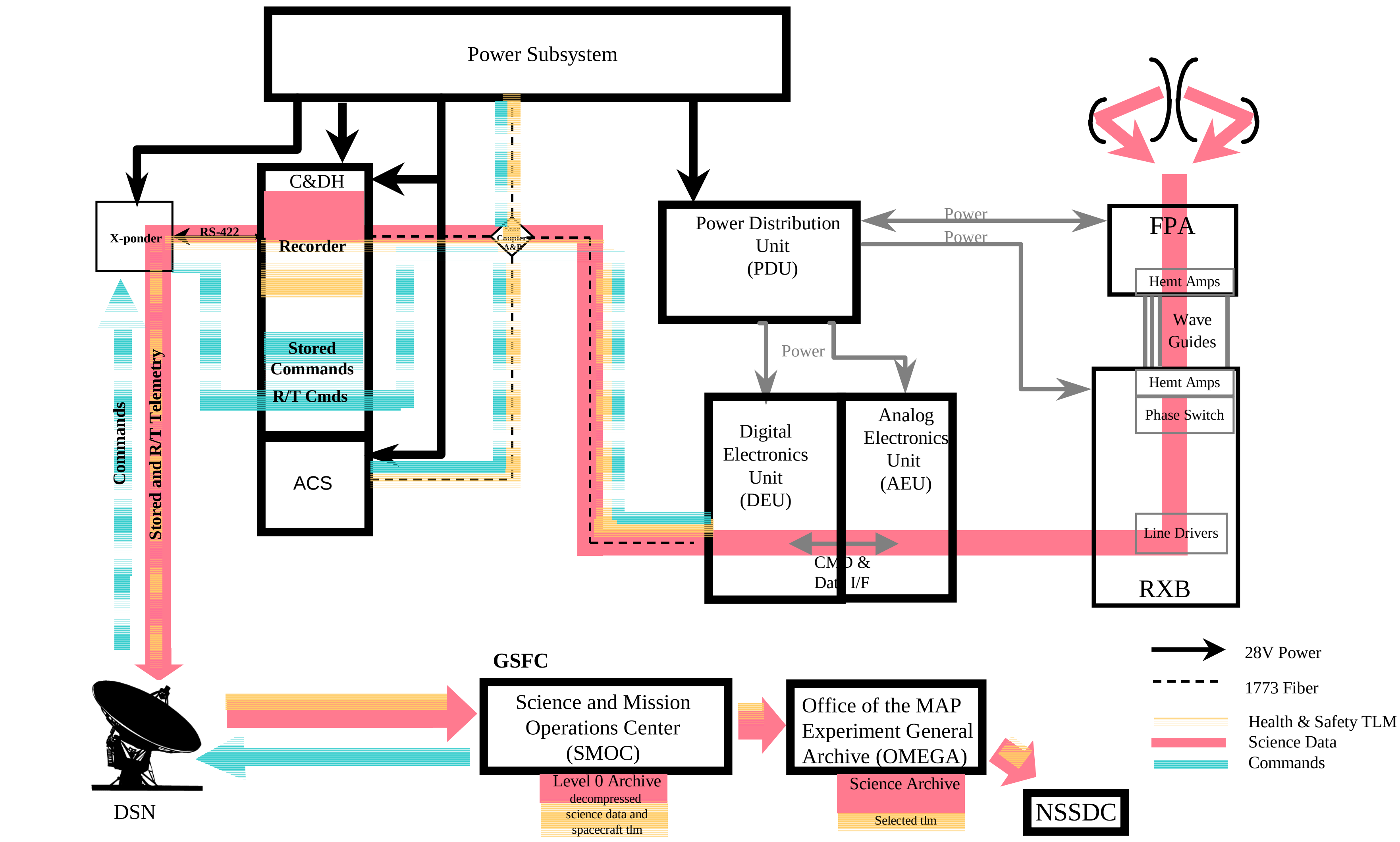
MAP’s Scan Strategy

- **6 Months for full sky coverage**



MAP Data Flow

Flight Operations Review



Observing

- One 37 minute pass/day-DSN 70m antenna
- On-board data storage utilized
  - Science data compressed and stored along with S/C health and safely telemetry
  - On-board recorder provides ~two days worth of data storage
- Nominal downlink rate of 666 Kbps
  - Downlink real-time and stored data
- Uplink at 2 Kbps
  - Real-time and stored command capability
  - Supports relative time and absolute time command sequences
  - Single stored command load per week planned for DSN contacts

MAP Downlink Rates

CMD	Downlink Bit Rate Rate	Usage / Function	Packet BPS	Realtime (VC0) BPS	Playback (VC1 to VC3) BPS
4	1,200,000	Prime Mission L2 Rate 1/4 -2.4 dB	1,020,000	32,000	988,000
5	1,000,000	Prime Mission L2 Rate 1/4 -1.6 dB	850,000	32,000	818,000
6	857,143	Prime Mission L2 Rate 1/4 -0.9 dB	728,572	32,000	696,572
7	750,000	Prime Mission L2 Rate 1/4 -0.4 dB	637,500	32,000	605,500
8	**666,667**	**Prime Mission L2 Rate 1/4**	566,667	32,000	534,667
9	600,000	Prime Mission L2 Rate 1/4 +0.6dB	510,000	32,000	478,000
10	545,455	Prime Mission L2 Rate 1/4 +1.0 dB	463,637	32,000	431,637
12	461,538	Backup Mission L2 Rate 1/2	392,307	32,000	360,307
26	**222,222**	**Moon to Med Gain**	188,889	32,000	156,889
59	**100,000**	**Launch to Moon**	85,000	32,000	53,000
966	**6,205**	**Emergency Omni**	5,274	5,274	0
2999	**2,000**	**TDRS & Power on Default**	1,700	1,700	0
186	**32,086**	**I&T realtime, Realtime only**	27,273	27,273	0

MAP Mission Downlink Rate

3573	**Instrument Record Rate BPS (VR3)**
2750	**S/C Record Rate BPS (VR1)**
666667	**Total RF Link Bit Rate BPS**
3500	**Assigned VC 0 Bit Rate BPS**
750	**Margin for VC0 Async BPS**
563167	**Playback Packet Bit Rate BPS (VR1, VR3)**
9.1	24 Hr Science Playback Time Min
7.0	24 Hr S/C Tlm Playback Time Min

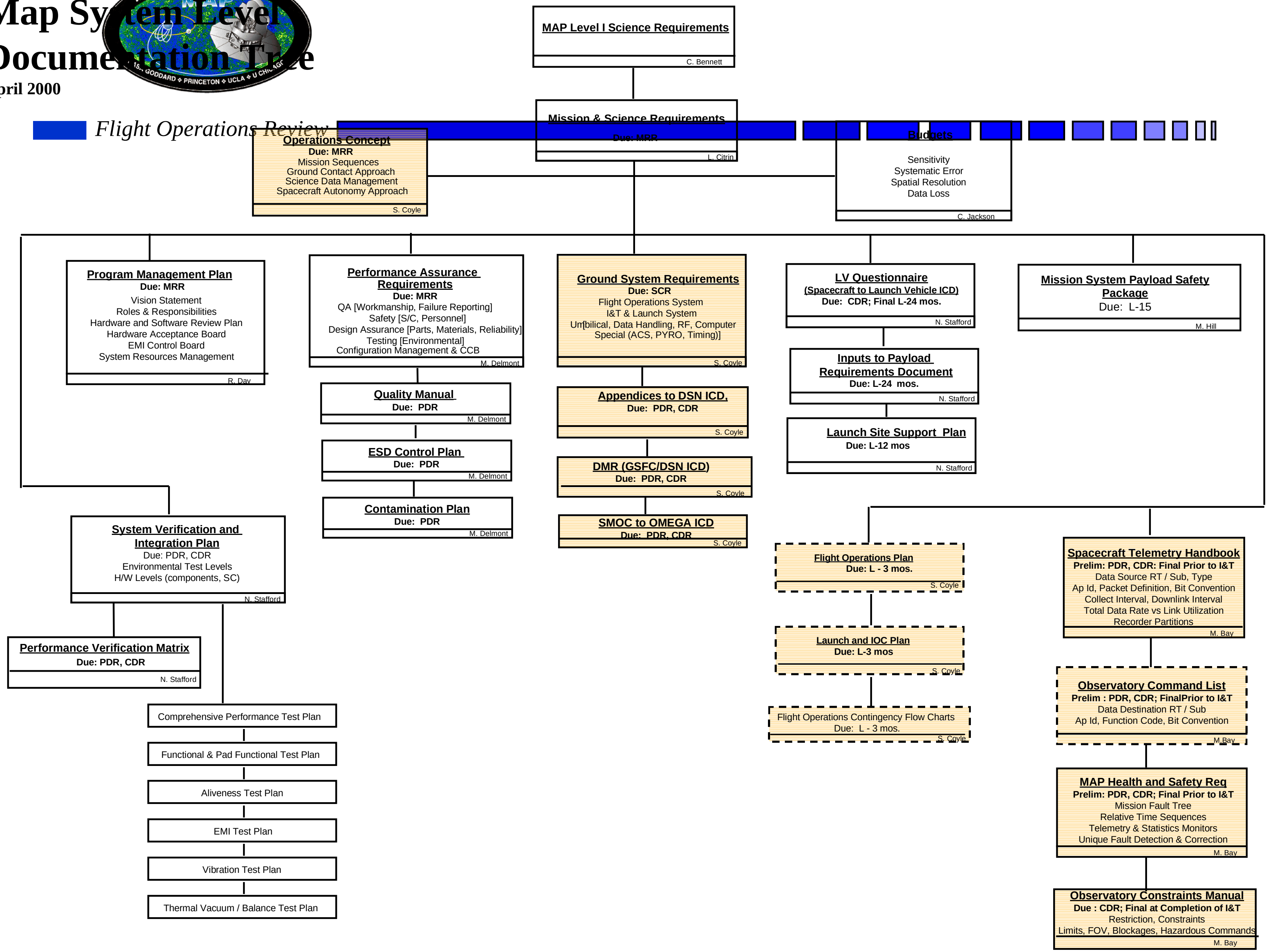
Table 8.2 MAP VC0 Packet Summary

8/18/99
Build 2.3

			Interval / Rates						
			Telemetry				Archive		
			Miss	Engr	Launch	TDRS	Miss	Engr	Launch
			1	2	3	4	1	2	3
		Allocation:	(2750)	(16000)	(16000)	(1700)	(2750)	(16000)	(16000)
	Total Filter Bit Rate		**2613**	**13791**	**14235**	**1650**	**2603**	**13791**	**14235**
ACE	**Subsystem Filter Bit Rate**	500	**311**	**3036**	**3030**	**286**	**311**	**3036**	**3030**
ACS S/W	**Subsystem Filter Bit Rate**	900	**1231**	**4159**	**4159**	**431**	**1221**	**4159**	**4159**
Comm	**Subsystem Filter Bit Rate**	160	**150**	**472**	**460**	**139**	**150**	**472**	**460**
Deploy	**Subsystem Filter Bit Rate**	10	**5**	**5**	**624**	**156**	**5**	**5**	**624**
FDS S/W	**Subsystem Filter Bit Rate**	180	**241**	**433**	**433**	**129**	**241**	**433**	**433**
Hskpng	**Subsystem Filter Bit Rate**	290	**153**	**191**	**185**	**48**	**153**	**191**	**185**
Inst	**Subsystem Filter Bit Rate**	150	**192**	**201**	**195**	**50**	**192**	**201**	**195**
Prop	**Subsystem Filter Bit Rate**	10	**10**	**1248**	**1248**	**78**	**10**	**1248**	**1248**
PSE	**Subsystem Filter Bit Rate**	200	**322**	**502**	**356**	**293**	**322**	**502**	**356**
Spare	**Subsystem Filter Bit Rate**	350		**3546**	**3546**	**40**		**3546**	**3546**

Map System Level Documentation Tree

April 2000



Map System Level Documentation Tree

April 2000

- **Mission & Science Requirements** — Due: MRR — L. Citrin

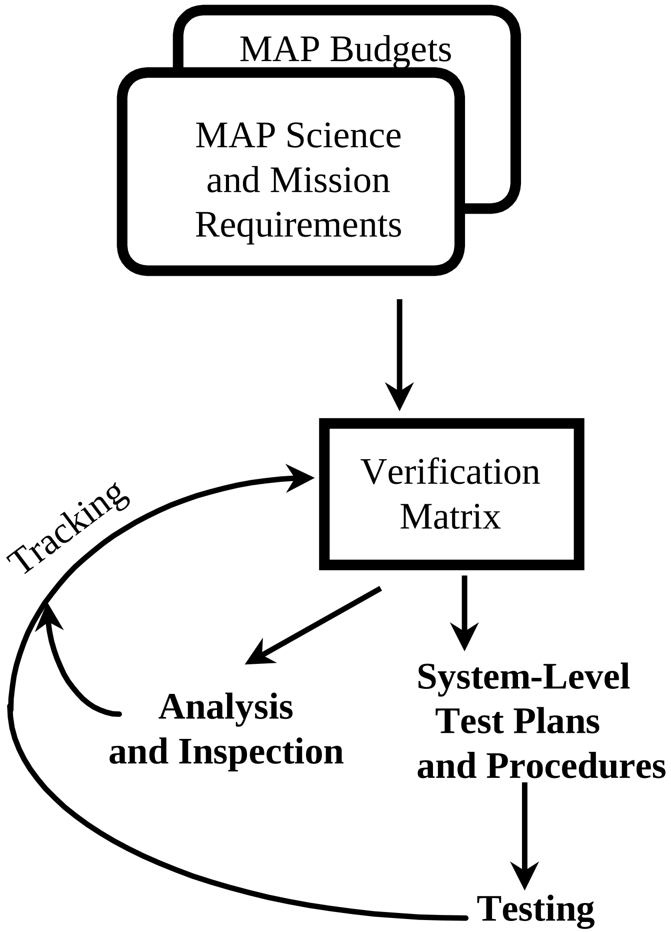
Flight Operations Review

- **Electrical Systems Specification** — Due: SCR
  - Grounding Philosophy & Req (S/C & GSE)
  - Power Switchinh, Distribution Philosophy
  - Power Protection Philosophy & Req
  - Power System Voltage Range
  - Power Service EMI, Transients, Noise & Ripple
  - Shielding Philosophy & Req
  - Total Dose & SEU Requirements
  - G. Won
  - **Wiring & Fusing Analysis** — Voltage Drops, wiring protection — K. Castell
  - **FMEA's** — G. Won
  - **Electrical Interface Analysis** — G. won
  - **Pig-tail/Star Coupler Spec** — A. Coleman
  - **Distribution and Grounding Diagrams** — G. Won
  - **Harness Drawing** — A. Coleman
- **Observatory Mechanical Specification** — Due: PDR, CDR — Observatory Structure — J. Stewart
  - **Observatory Thermal ICD** — Due: PDR, CDR — J. Stewart
  - **Deployables System Specification** — Due: PDR, CDR — J. Stewart
  - **Mechanical/Thermal Resources** — Weight and CG; Temperature Predicts
  - **Observatory Mechanical ICD** — Due: PDR, CDR
- **Command and Data Handling Specification** — Due: PDR, CDR — J. Ruffa
  - **C&DH Software Specs** — J. Marquart
  - **C&DH System Resources:** — Memory Utilization; CPU Utilization; Bus Utilization; Downlink Bandwidth Utilization; Recorder Utilization
    - **1773 Bus ICD** — Due: PDR, CDR — J. Marquart
- **Communications System Specification** — Due : PDR — M. Powers
  - **Transponder Specification**
  - **Antenna Specification**
  - **DSN Letter of Agreement**
  - **Transponder to ESN ICD**
  - **RF Component Specs**
  - **RF System Resources:** — RF Link Budgets
- **Propulsion System Specification** — Due : PDR, CDR — G. Davis
  - **Propulsion Component Specs**
  - **Propulsion Resources:** — Propellant Budget
  - **Propulsion ICD** — Due: PDR, CDR
- **Power System Specification** — Due: PDR, CDR — B. Beaman
  - **Pse Specification**
  - **Battery Specification**
  - **Solar Array Specification**
  - **PSE Software Specification** — J. Marquart
  - **Power System Resources:** — Solar Array Budget; Mission Mode Power
    - **LVPC Users' Guide/ICD** — Due: PDR
- **Attitude Control System Specification** — Due : PDR, CDR — D. Ward
  - **ACS Component Specs**
  - **ACE Spec and ICD**
  - **ACS Software Requirements Document** — M. Walters
  - **ACS System Resource Budgets:** — Knowledge; Jitter; Attitude Control
- **PDU Specification** — Due: PDR, CDR — C. Kellenberg
- **AEU Specification** — Due: PDR, CDR — D. Bergman
- **DEU Specification** — Due: PDR, CDR — R. Bourelli
- **Instrument S/W Specification** — C. Trujilla
- **Thermal/Reflector System Specification** — Due : PDR — J. Stewart
- **Feed Specification** — Due: PDR, CDR — L. Page
- **Differencing Assemblies Specification** — Due: PDR, CDR — N. Jarosik

Mission Requirements

#	Title	Functional Requirement	Performance Requirements
2.2	Mission Life	Mission life shall be sufficient to achieve the time on target to meet the sensitivity requirements, as well as	The mission life shall be 27 months.
2.3	Data Loss	Science data losses shall be sufficiently limited to meet the sensitivity and sky coverage requirements.	Data losses throughout the system from instrument detection through delivery to the PI shall not exceed 10%.
3.5.1	Orbit		Conduct the bulk of science observations in a 1 - 10 deg Lissajous orbit about the Sun/Earth second Lagrange point (L2).
5.5.1	Trajectory	The launch vehicle shall deliver the observatory to a transfer trajectory from which an observatory supplied propulsion system shall deliver the observatory to L2.	The launch vehicle shall provide a 708 kg throw weight to a 28.7 deg (ETR) inclination orbit with a C3 of -2.6 and a minimum perigee of 1000 km.
6.4.1	Delta-V Maneuvers	Provide the capability for trajectory correction and orbit maintenance.	At L2, Delta-V maneuvers shall be in concert with momentum maneuvers.
6.4.5			For all maneuvers except stationkeeping and momentum management maneuvers at L2, the observatory shall be oriented such that the thrust vector remains aligned with the velocity vector.
6.5.3	Delta-V Maneuver Predictability	The execution of delta-V maneuvers shall be sufficiently predictable to achieve the required mission trajectory within the propellant allotment.	Uncertainty due to ground system modeling errors shall be limited to 1%.
6.6	Delta-V Budget	Provide sufficient Delta-V budget for the life of the mission.	
6.6.1			Delta-V of 1 m/s shall be provided for thruster calibration.
6.6.2			Delta-V of 10 m/s shall be provided to accommodate a daily 20-minute launch window.
6.6.3			Delta-V of 60 m/s shall be provided for trajectory maneuvers.
6.6.4			Delta-V of 15 m/s shall be provided for final perigee maneuver correction.
6.6.5			Delta-V of 10 m/s shall be provided for a mid-course correction maneuver.
6.6.6			Delta-V of 4 m/s shall be provided for stationkeeping for each year of observing at L2.
6.7.3	Momentum Management	Provide for necessary momentum maintenance.	At L2, momentum maneuvers shall be limited to <= 4 per year, and shall not interrupt the observing mode for more than 3 (TBR) hours.

REQUIREMENTS VERIFICATION



- Verification of each requirement is allocated to Inspection, Test and/or Analysis
- Database tracks verification method, tests, test results, analysis and inspection reports
- Database exists with verification method and test name and description for testable requirements
- Test results tracking is ongoing as subsystem and system level testing progress
- Analysis/inspection tracking is in progress

Requirements and Verification Data Base

Flight Operations Review

Requirement Table

Rqmt #	Requirement
...	
6.1.1	The sun shall be ...
6.1.2	Deleted
6.1.3	Sun acquisition ...
6.2	Implement a comp...
6.2.1	A 2.47-2.5 deg/sec ...
...	

Test Verification Traceability

Rqmt #	How Tested
...	
6.1.1	ACS12
...	
11.3.2	CDH17

Test Data Base

Test	Test Title	-Description -Pass/Fail Criteria -Procedure -GSE ...
CDH01	1773 Bus Communications	
CDH02	1773 Optical Margin	
CDH03	1773 Single Event Upset Simulatio	
...		

Allocation Table

Rqmt #	Subsystem
...	
6.2.1	ACS
6.2.2	ACS
...	

Analysis Verification Traceability

Rqmt #	Analysis Report
6.7.3	**Solar Pressure and Pinwh** **MAP-ACS-ENG-SUB-866**
...	
8.1.1	Radiation Reports

Tracking Table

Rqmt #	Test Results
...	
6.2.1	Pass
6.2.2	PFR #
...	

MAP Attitude Control System

David Ward

MAP ACS Summary Chart

Science Mode Pointing

- Zero-momentum COBE-type control
- Spacecraft spin rate: 2.78 °/s;
- Precession rate: 0.1 °/s;
- Pitch offset: 22.5° +/- 0.25°
- Maps the entire celestial sphere twice in one year

Orbit

- Earth-sun L2 point, to minimize environmental disturbances to instrument
- Lunar assist injection, requiring 70m/s delta V from spacecraft RCS (120 minute burns)
- Stationkeeping to maintain 1° to 10° Lissajous orbit
- Lack of magnetics requires thruster-based momentum unloading

Architecture

- Mongoose V processor, 1773 data bus, using ACE for sensor/actuator interfaces
- Distributed power switching, housekeeping

Attitude Determination

- On-board, using Kalman Filter processing of ST, DSS, IRU
- ACS on-orbit allocation: 1.3 arcmin, RMS

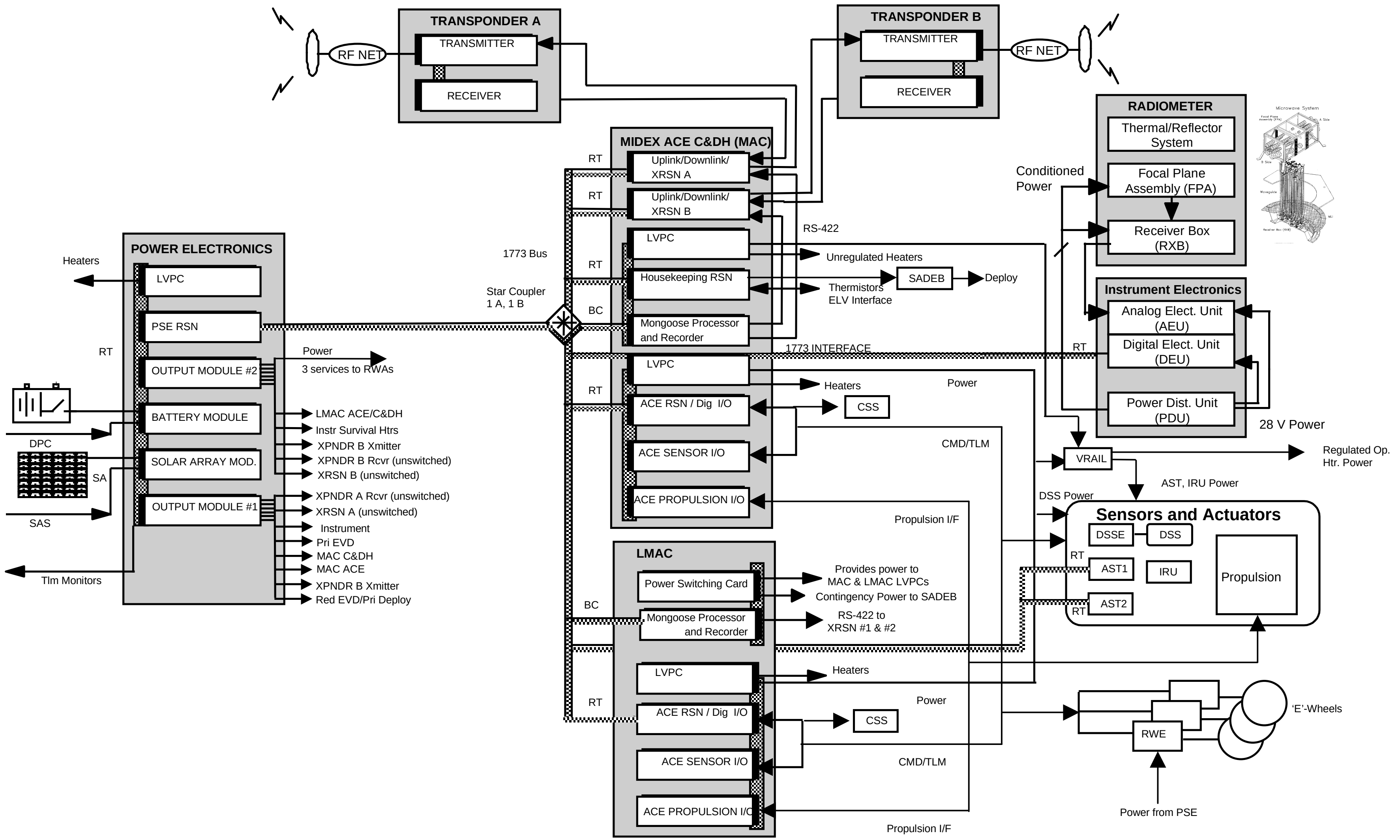
SafeHold

- Maintained in ACE, independent from primary control algorithm
- Uses CSS, RWAs and optionally IRU
- Acquires sun within 25° in 35 minutes

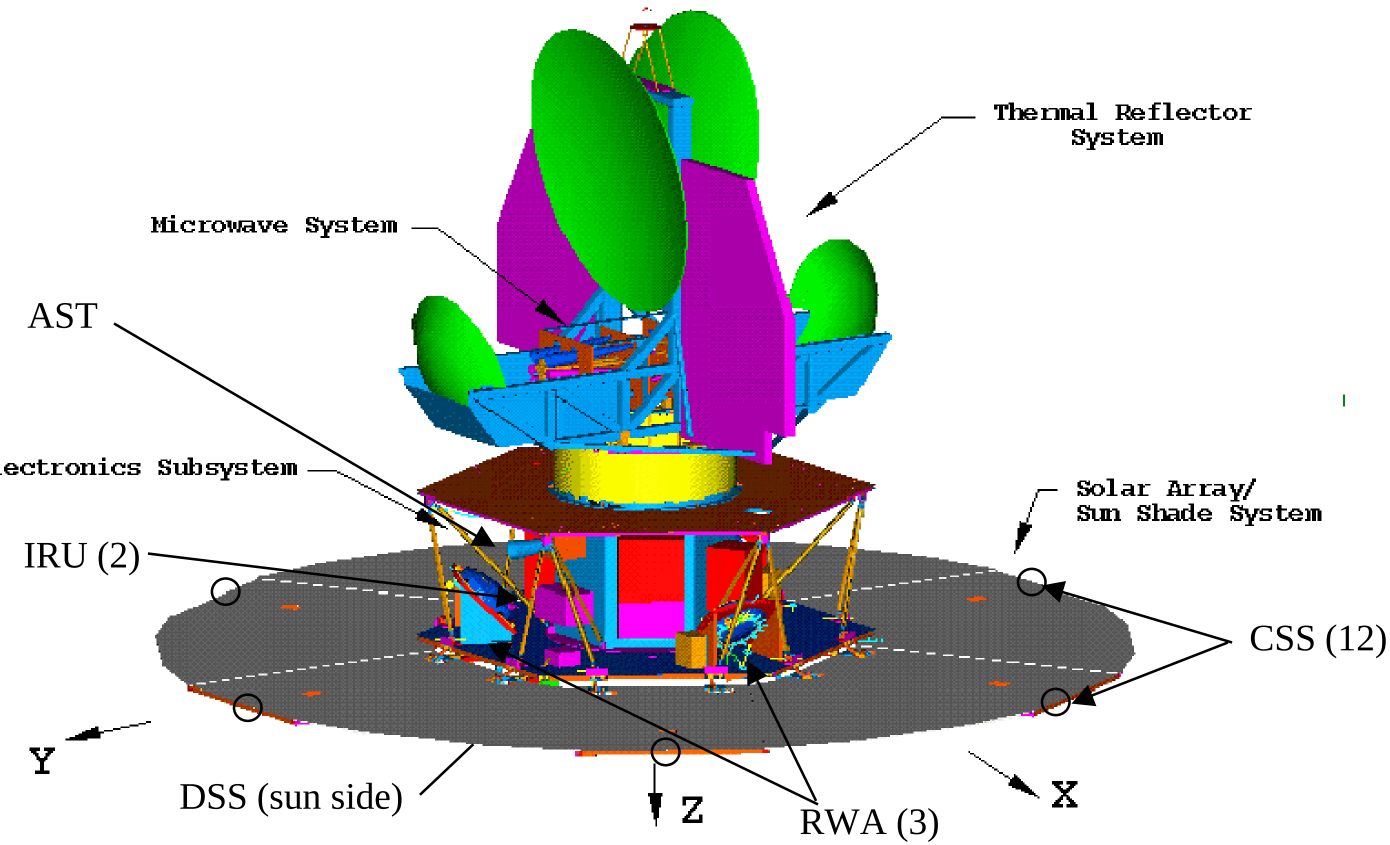
Sensor/Actuator Complement

- Two Lockheed AST 201 Star Trackers
- Two Kearfott TARA Inertial Reference Unit
- Adcole 128°X64° Digital Sun Sensor
- Twelve Adcole Coarse Sun Sensors
- Three Ithaco E-Reaction Wheels
- Eight 4.45 N Thrusters
- MIDEX Attitude Control Electronics

MAP Architecture

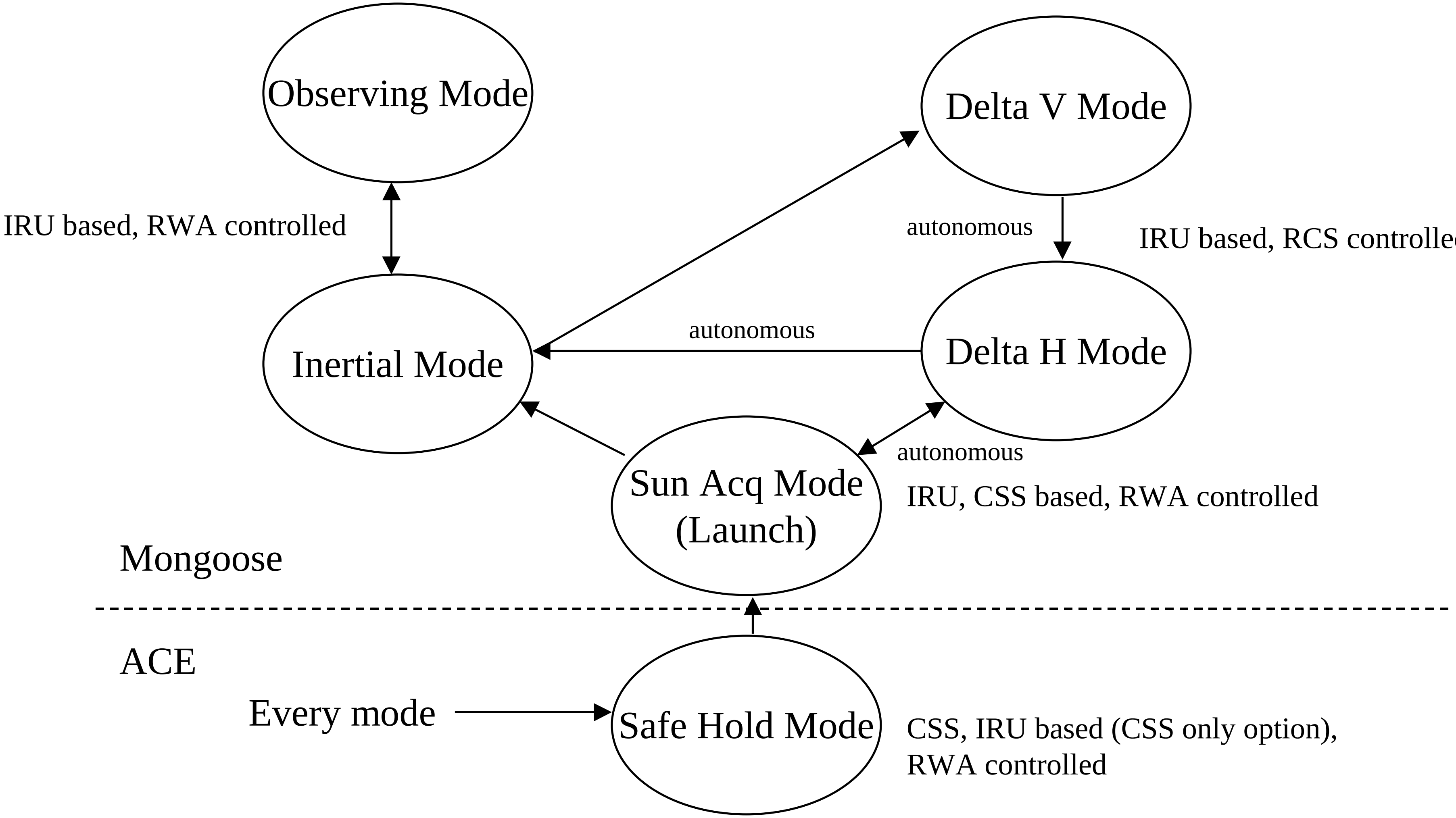


MAP Spacecraft



MAP - DEPLOYED CONFIGURATION

Mode Diagram



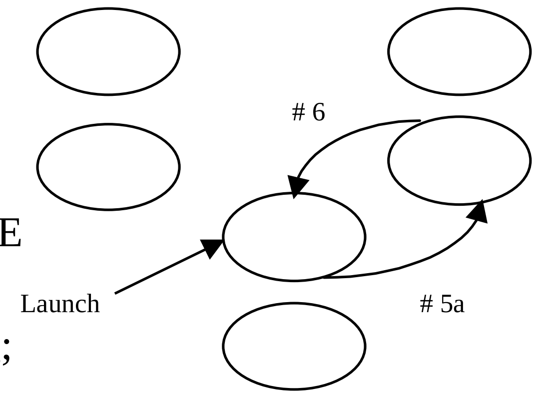
Mode Summary

Mode	SafeHold	Sun Acquisition	Inertial	Observing	Delta V	Delta H
Purpose	Acquire the sun in the event of anomalies	Acquire the sun at launch, from SafeHold	Stable pointing, reorientation slews	Perform all-sky scan	Orbit adjust, stationkeeping	Unload momentum
Sensors	CSS, IRU	CSS, IRU	Updated IRU	Updated IRU	Propagated IRU	Propagated IRU
Actuators	RWA	RWA	RWA	RWA	PCS	PCS
Attitude Determination	None	None Init Kalman filter	Kalman Filter	Kalman Filter	propagate q, P	propagate q, P
Control Error	Sun angle error, measured or derived rate	Sun angle error, rate	quaternion, rate	quaternion, rate	quaternion, rate	system momentum integrated rate
Control Law	PD	PD	PD	PD	PD, PWM	PD, PWM

Sun Acquisition Mode

- Sun Acq is used to initially despin the spacecraft after separation and point the spacecraft +Z axis toward the sunline
- Simple control law requires six (three pointed sunward, three pointed anti-sunward) Coarse Sun Sensors for position and IRU for rate
- No special commands are designed specifically for Sun Acq
- At launch, if tip-off rates are high (> 8.0 degrees/second), ground will command from Sun Acq directly into Delta H for momentum unload, then return to Sun Acq autonomously
- This mode is also used for the first step from Safe-Hold recovery, as well as a thermal and power-safe mode in the event of power or minor ACS anomalies that don’t require Safe-Hold
- Generally, the Kalman filter (attitude determination system) is initialized in Sun Acq

Operations:
Launch and Acquisition



1) Spacecraft launches in Sun Acquisition, with RWAs off
2) Delta II performs yo-yo spin-down to ± 2 RPM
3) ELV separation sensed by Housekeeping RSN, which deploys Solar Arrays, ACS remains in Sun Acquisition mode, PSE and Mongoose command wheels on
4) H/K RSN relays sep switch to ACE, enabling wheel commanding; Sun Acquisition performs rate damping
5) Upon Solar Array deployment (sensed in ACE), ground uses telemetry to compute tip-off momentum

5a) If high, mode switch to Delta H via ground command (limited to 5 seconds to prevent spin-up)

5b) If low (< 2 sigma), complete sun acquisition

6) After Delta H, mode switch back to Sun Acquisition and acquire

Anomalies

- If entry into SafeHold, SafeHold/IRU controller will acquire within 35 minutes for up to 2 sigma rates

Inertial Mode

- Inertial mode is a higher-performance pointing mode used as a stepping stone to Observing Mode and to Delta V mode
- The initial command quaternion is set to the attitude estimate when Inertial is entered
- New command quaternions can be uplinked three ways:
  - Raw quaternion commands
  - Use of a command quaternion table, which allows for several attitudes to be commanded at once, along with the absolute command time
    - Table can be used for 499 separate quaternions
    - Maximum number of quaternions needed is 200 during perigee burns
  - Two pre-canned functions, which create quaternions at known offsets to the sunline
    - ACSSLEWSUNSAFE: on sunline
    - ACSSLEWSCANANGLE: 22.5 degrees off sunline
- Entrance to Observing Mode comes from Inertial, when attitude determination is deemed valid and attitude is 22.5 degrees from sunline

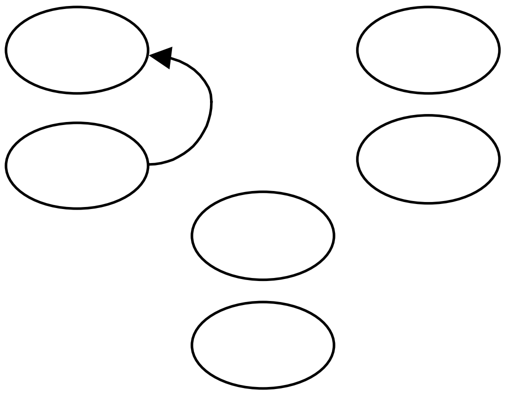
Observing Mode

- Observing Mode is our science mode, and the mode which we will spend 95%of time in after the lunar swingby
- Observing Mode states (kept in an ACS table) are used to create a moving command attitude in the ACS software
- To prevent excursions of > 25 degrees off the sunline, an Observing Mode command is not accepted unless spacecraft is 22.5 +/ 0.25 degrees from the sunline, and initial state is a first-order ramp-up to the 2.7 degree/second spin rate
- One special command exists for Observing Mode:
  - ACSLOADSOLARBIASQ--ability to offset scan from sunline
  - Can be used to offset momentum build-up, but baseline plan is not to bias at all
- When exit is needed from Observing, a first-order ramp-down is used to get rates near zero before going to Inertial
  - It is possible to sit in Observing without scanning, but generally, command down to low rate is followed by command to Inertial Mode

Operations: Inertial/Observing Mode

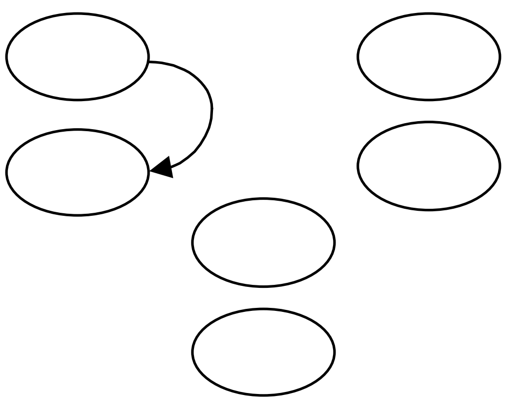
Entering Observing Mode

- Only by ground command from Inertial Mode
- To prevent overshoot, spacecraft should be at offset pointing (22.5 degrees from the sunline) prior to change: use Inertial slew to go to 22.5 offset
- Final survey rate reached through a first order rate command filter, to control ramp-up
- Spacecraft spins up in Observing Mode



Returning to Inertial Mode

- From Observing Mode, only by ground command (can be entered from other modes, like Delta H, autonomously)
- Spacecraft spins down in Observing Mode "Spin-down" state, then can be commanded to Inertial Mode

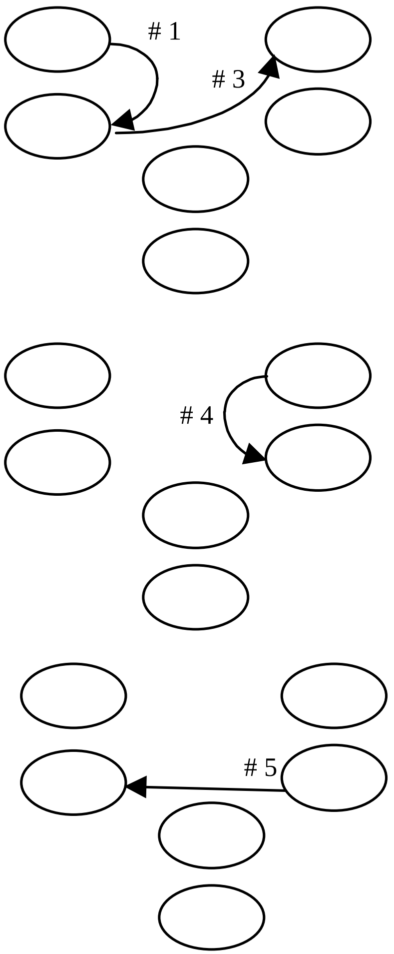


Thruster Modes (Delta V and Delta H)

- Delta V is the mode used to change the orbit by adding velocity in a certain direction
  - Command format includes X and Z duration, which represent Force-normalized durations for an “ideal” burn
  - -Z duration uses thrusters 1&2, +Z duration uses thrusters 3&4
  - Thruster cant angles and duty-cycling are accounted for on-board, to ensure “ideal” burn duration is achieved
  - A separate table value is compared to the total length of the burn to stop a burn that lasts several minutes too long
  - Target attitude for Delta V is command quaternion at entrance to mode, but can be updated by use of Command Quaternion Table described in Inertial Mode chart
- Delta H is the mode used to unload system momentum
  - Entered autonomously at the end of Delta V
  - Also entered by ground command (whose structure includes the target momentum) as needed, such as after separation to unload tip-off momentum
  - Exits autonomously to either Sun Acq (if commanded from Sun Acq) or Inertial (if commanded from Inertial or entered autonomously from Delta V)
  - Exit is either based on achieving target momentum within 0.3 Nms tolerance or at end of 5 second timeout

Operations: Delta V

0) Spacecraft receives pre-checked commands to enter Inertial Mode, slew to burn position, and conduct a Delta V of a specified length. Configuration commands (Cat Bed Htr control, etc) and target Q's (in Command Quaternion Table) are uploaded at the same time.
1) At the appointed time, spacecraft enters Inertial Mode, then slews to first target Q.
2) Before the burn, CQT is enabled to start tracking predefined path
3) At burn time, spacecraft enters Delta V mode
4) At end of burn, spacecraft autonomously enters Delta H mode to unload excess momentum.
5) When excess momentum is unloaded, spacecraft enters Inertial Mode at previous target Q, unless it has been updated.
6) CQT is disabled and spacecraft returns to normal operations



Safe-Hold Mode

- Safe-Hold is the independent, sun-safe, power-safe controller resident in the Attitude Control Electronics
- Safe-Hold uses the Coarse Sun Sensors for position signal, and control spacecraft to point +Z at the sunline
- Two different algorithms are resident on each ACE: SH/IRU, which uses the IRUs for rate, and SH/CSS, which derives rate from the CSS
  - SH/IRU is more robust to high momentum conditions, so is used for launch
  - SH/CSS is more robust to different component failures, so is used when commanded by FDC
- Entrance to Safe-Hold is either by a ground command, loss of the “I’m OK” coming from the Mongoose, or by autonomous commanding via ACS FDC
- Exit from Safe-Hold must be via command, and is always into Sun Acq control on the Mongoose
- If momentum unloading is required during an extended stay in Safe-Hold, provisions exist to fire thrusters for 1 second at a time via ground commands, but no autonomous thruster control exists in Safe-Hold

Additional ACS Functionality

- Attitude determination
  - Kalman filter that uses Autonomous Star Trackers and Digital Sun Sensors to update the attitude and Inertial Reference Unit biases
  - Attitude is initialized by ground command that allows replacing the attitude estimate with the estimate generated by the selected AST
    - In order for AST estimate to be used for initialization, multiple contiguous quaternions must match within a tolerance, and the AST quaternion must be deemed valid by the AST itself, as well as the ACS software
    - Once attitude is initialized, it is propagated by gyro rates until the Kalman filter is enabled or another valid AST quaternion is available
  - Normal Kalman filter operations require only periodic monitoring to ensure AST and DSS inputs are being used for updates
  - Ability exists on-board to reset the Kalman gains, which allows for the most recent updates to be weighed more heavily than would be with a "steady-state" Kalman filter (used when a Z axis gyro switch is performed by FDC, for example)
  - Kalman filter can only be started while in Inertial/Settled or Sun Acquisition/Acquired/Modes
- Ephemeris
  - Observatory, solar, and lunar models are used on-board
  - Lunar and solar models are mathematical, and require no more than annual table updates
  - Observatory model requires weekly EPV (epoch time, in seconds since 1/1/93, GCI position in meters, and GCI velocity in m/s)

Special Early Operations

- Initial acquisition and momentum unload
- Thruster polarity checkout, using ground commands
- Safe-Hold checkout (both SH/IRU and SH/CSS)
- Transfer control to LMAC
- Inertial slew/CQT checkout
- IRU calibration slews
- Slow Observing scans for DSS/AST calibrations
- Thruster calibration burns (using Delta V mode)
- Perigee Delta V maneuvers

Normal Operations/Periodic Commands

- Spacecraft can stay in Observing Mode for several days without interruption
- Weekly ephemeris commands to keep on-board ephemeris from going stale
- Monthly/quarterly updates to tables of the gyro bias estimates, if needed:
  - Kalman filter will calculate the correction, but it's best to keep the table values as close as possible to the estimate to minimize KF convergence problems
  - Ensures correct bias is used as starting point if KF reset is needed
- Quarterly stationkeeping Delta V maneuvers and Delta H momentum unloads

Key Data to Monitor

- On-board Failure Detection & Correction monitors attitude performance, sun constraints, and component failures and can autonomously safe the spacecraft if needed
- Key items for ground to trend/monitor:
  - System Momentum magnitude: predictor of need for Delta H maneuvers, as Observing Mode does not work with H > 3.0 Nms
  - Telemetry from the "hot backup" ACE, to ensure functionality if there is a spacecraft anomaly
  - Gyro biases, motor currents, and temperatures as indicators of health of each unit
  - Wheel temperatures and calculated torque error to determine each RWA's health
  - Number of stars tracked and background noise, to ensure proper health (and TEC setting) of ASTs
  - Make sure AST and DSS providing continuous updates to the Kalman filter
  - Monitor FDC points, as a latched flag will note if there were any FDC failures, even if there wasn't enough persistence to require an autonomous action

Sensor Calibration

Rick Harman

Sensor Calibration

- Gyro Calibration
- Star Tracker/Sun Sensor Calibration
- Schedule

Sensor Calibration

- Gyro Calibration Delivery:
  - Scale Factor Corrections (uplinked to MAP)
  - Alignment Corrections (uplinked to MAP)
  - Bias (NOT uplinked since spacecraft estimates this parameter)
- Maneuver Rationale:
  - Need a minimum of 4 independent maneuvers to solve for all 12 parameters
  - Thermal Constraints require sun to be within 22.5 degrees of spacecraft +Z-Axis

Sensor Calibration

- Coarse Gyro Calibration
  - Calibrate out Coarse Gyro Errors Before Perigee Burn
  - Start with Sun Pointing Attitude
  - $\pm$ 30 degree Z-axis maneuver
  - $\pm$ 22 degree X-Axis Maneuver
  - $\pm$ 22 Degree Y-Axis Maneuver

Sensor Calibration

- Fine Gyro Calibration
  - Parameters for Science Observation Mode
  - Start with Sun Pointing Attitude
  - $\pm$ 90 Degree Maneuvers About Z-Axis
  - \+ 22 Degree Maneuver About X-Axis
  - $\pm$ 44 Degree Maneuvers About X-Axis
  - \- 22Degree Maneuver About X-Axis
  - \+ 22 Degree Maneuver About Y-Axis
  - $\pm$ 44 Degree Maneuver About Y-Axis
  - \- 22 Degree Maneuver About Y-Axis (return to Sun Pointing)
  - Maneuver Rate is 0.16 degrees/second

Sensor Calibration

- Star Tracker/Sun Sensor Deliveries (uplinked to MAP):
  - Star Tracker#1,2 Alignment Matrices
  - Digital Sun Sensor#1,2 Alignment Matrices
  - Digital Sun Sensor#1,2 Field of View Calibration Coefficients (12-alpha angle,12-beta angle for each Digital Sun Sensor)
- Maneuver Rationale:
  - Observe Sun throughout both sun sensor fields of view to enhance field of view calibration as well as alignment calibration
  - Allow for a multitude of stars to move throughout the fields of view as well as groups to transverse multiple portions of the field of view
  - Slower speed allows for more observations in the field of view and decreases gyro induced propagation errors

Sensor Calibration

- Star Tracker/Sun Sensor Calibration
  - Use Modified Observing Mode
  - 0.25 degree/sec rate about Z-Axis (2.5 degrees/second nominal)

Sensor Calibration

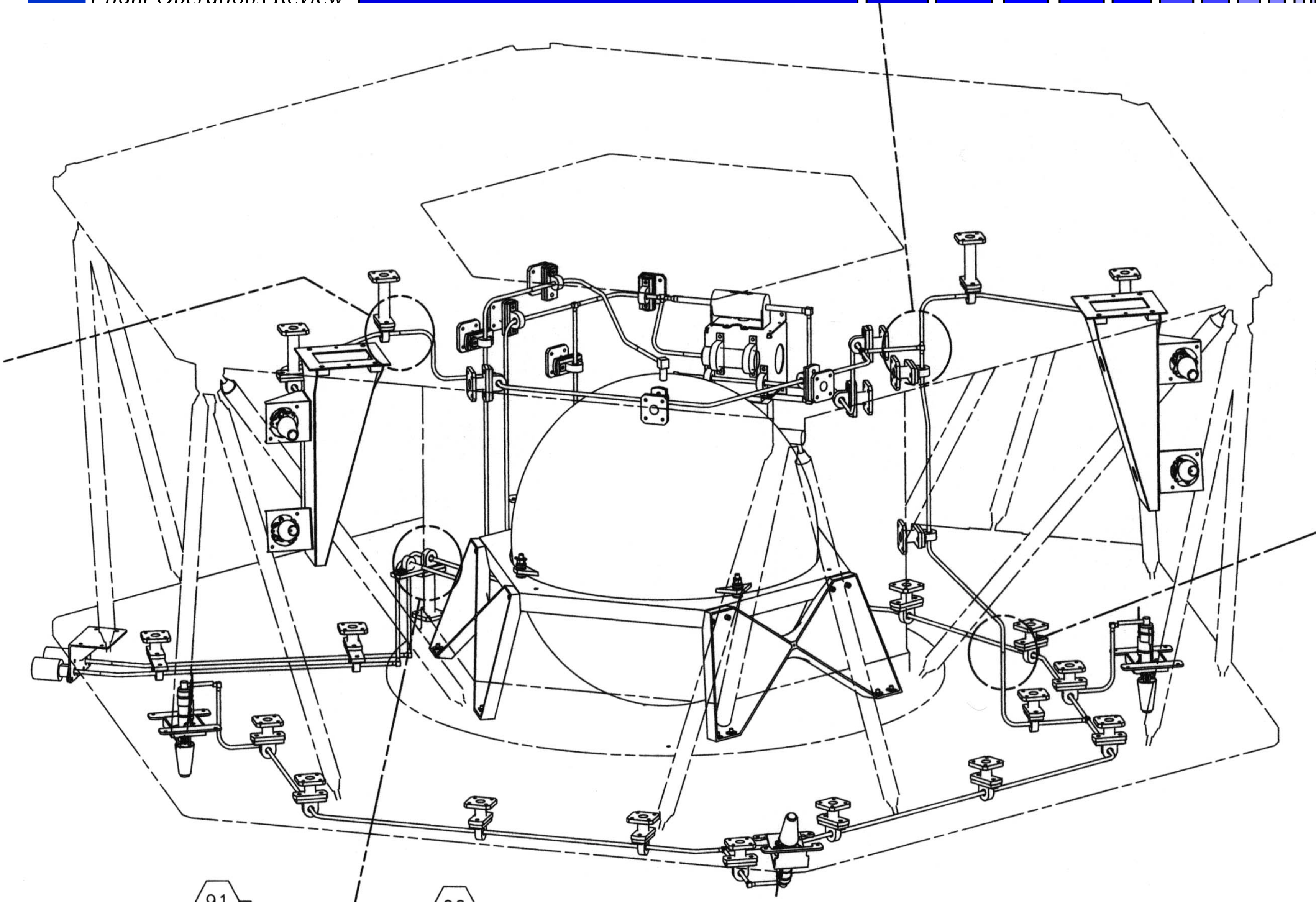
- Schedule
  - Day 2 (Coarse Gyro Calibration)
  - Day 3 (Deliver Preliminary Gyro Calibration Results-Prior to Perigee Maneuver)
  - Day 3 (Star Tracker-Sun Sensor Calibration)
  - Day 9 (Fine Gyro Calibration)
  - Day 22 (Deliver Final Gyro and Star Tracker Calibration Parameters)
  - Day 23 (Calibration Verification Using Fine Gyro Calibration Maneuvers)

Propulsion

Gary Davis

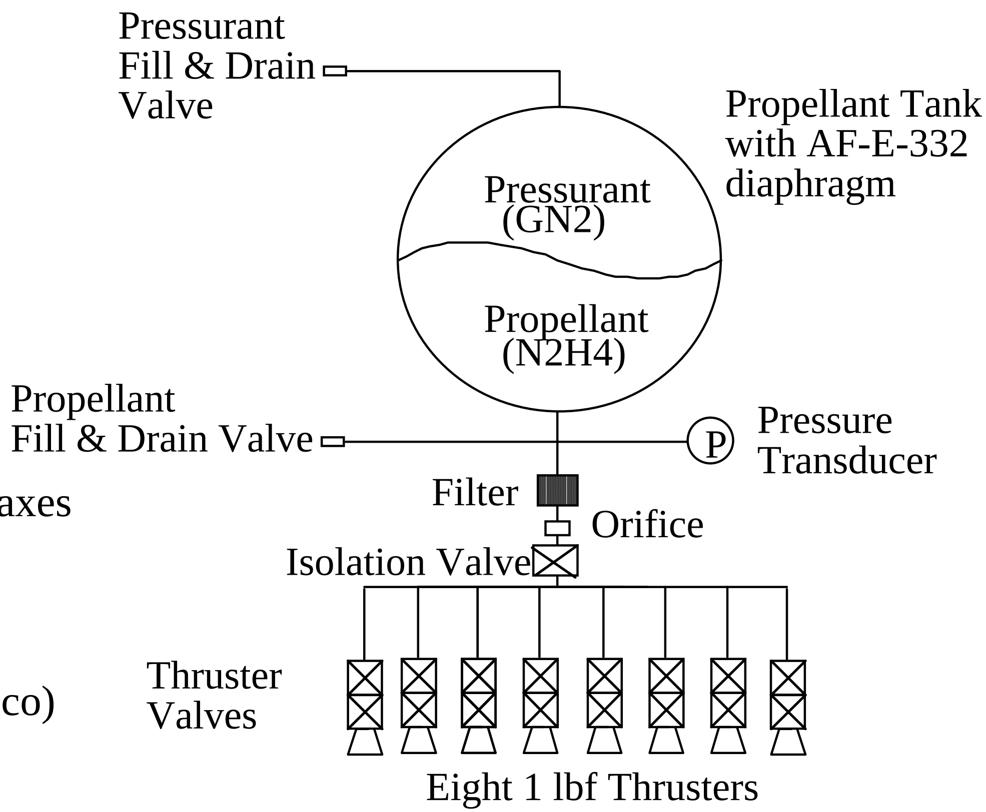
Propulsion Description

G. Davis / NASA GSFC 574

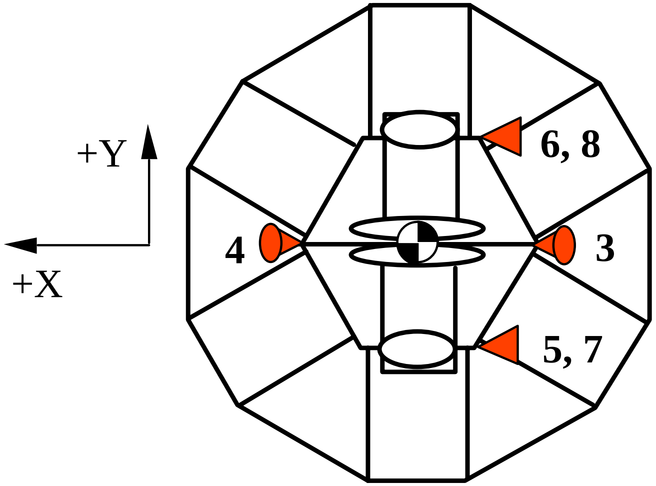


Design Overview

- Monopropellant hydrazine
  - Single diaphragm tank
  - 72 kg (160 lb) of N_2H_4
- Blowdown pressurization
  - MEOP = 350 psia
  - End of life = 80 psia
- 8 thrusters 4.45 N (1 lbf)
  - Provide Δ H & Δ V about all axes
  - Provide partial redundancy
- Other components:
  - Latching isolation valve (Vacco)
  - Pressure transducer (G-S)
  - 10 µ Filter (Vacco)
  - 2 Fill & Drain valves (Moog)
  - Surge suppression orifice



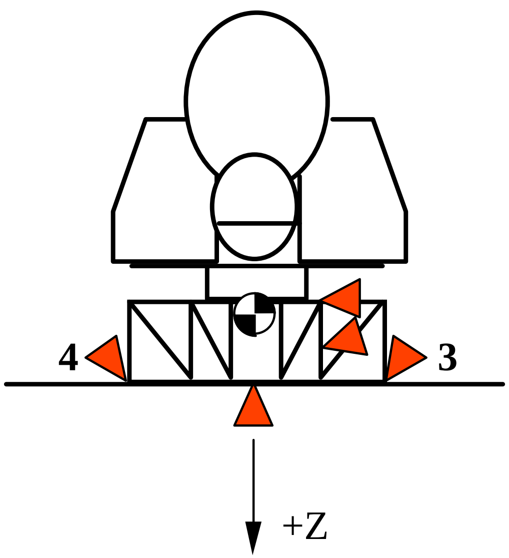
Thruster Locations / 1

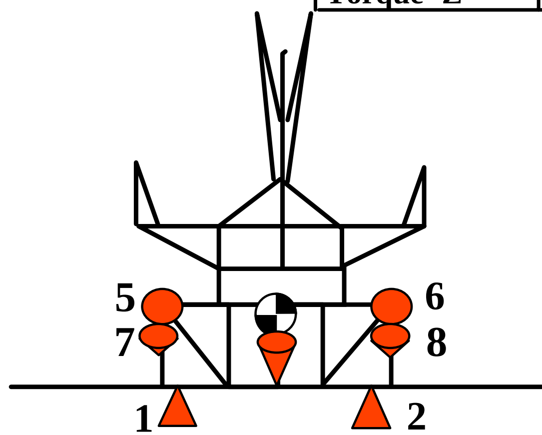


THRUSTER FUNCTIONS

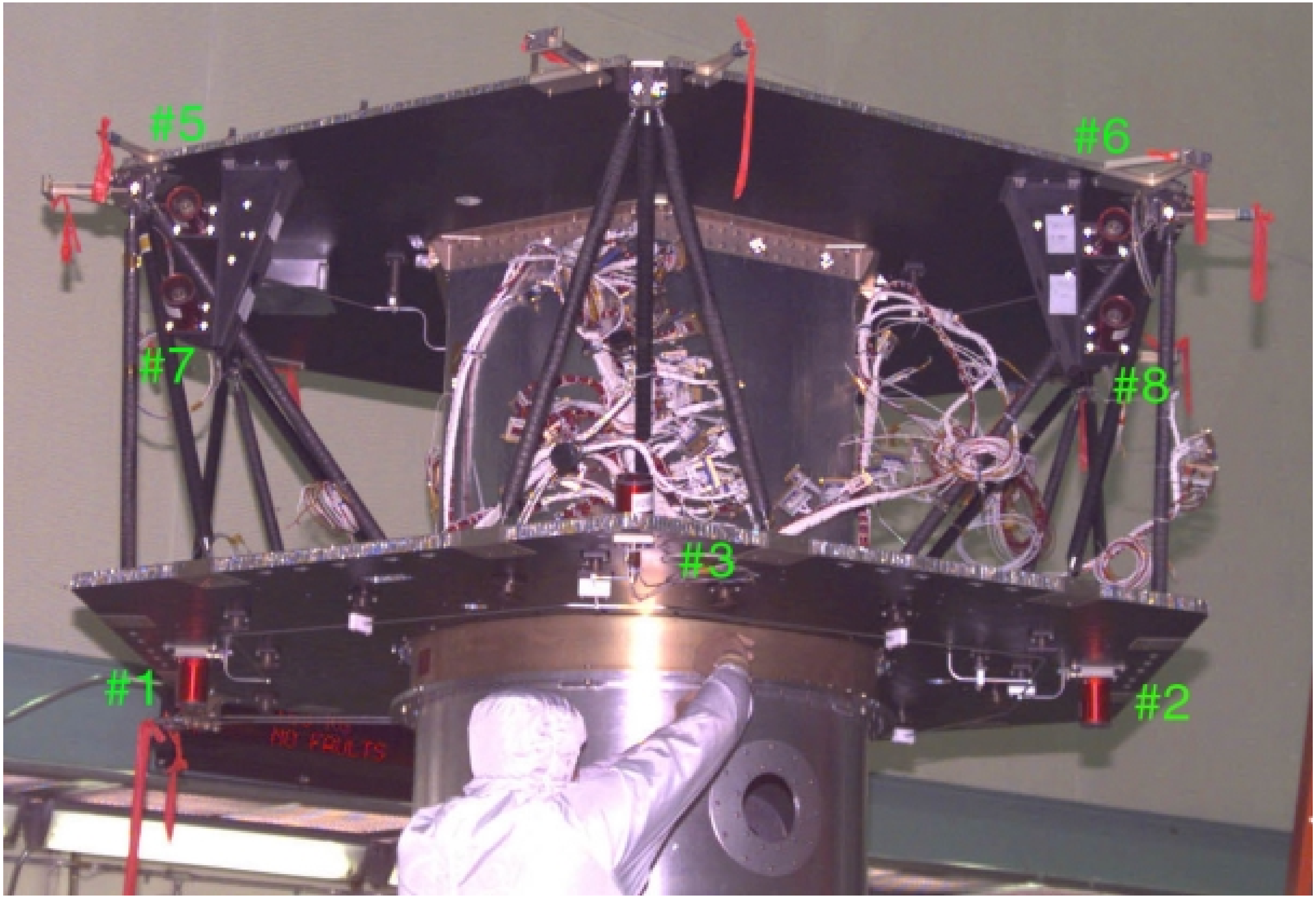
(X = primary mode;   B = backup mode)

Thruster #	1	2	3	4	5	6	7	8
Delta V +X					X	X	X	X
Delta V +Z			X	X				
Delta V -Z	X	X						
Torque +X	X							B
Torque -X		X					B	
Torque +Y			X				B	B
Torque -Y				X	B	B		
Torque +Z					X B		X B	
Torque -Z						X B		X B





Thruster Locations / 2



Activities During Operation

- Thrusters are only fired during Δ V and Δ H modes
- Daily activities: monitor telemetry
  - Tank pressure and temperature
  - Component / line temperatures
  - Isolation valve OPEN/CLOSE status
- Daily commands: (none)
- Periodic activities: Δ H and Δ V maneuvers
- Periodic commands:
  - Turn on catalyst bed heaters
  - Turn on valve driver power
  - Enable thruster set to be used in the maneuver
  - During Δ H or Δ V maneuvers, arm and fire thrusters

Health Monitoring / Trending

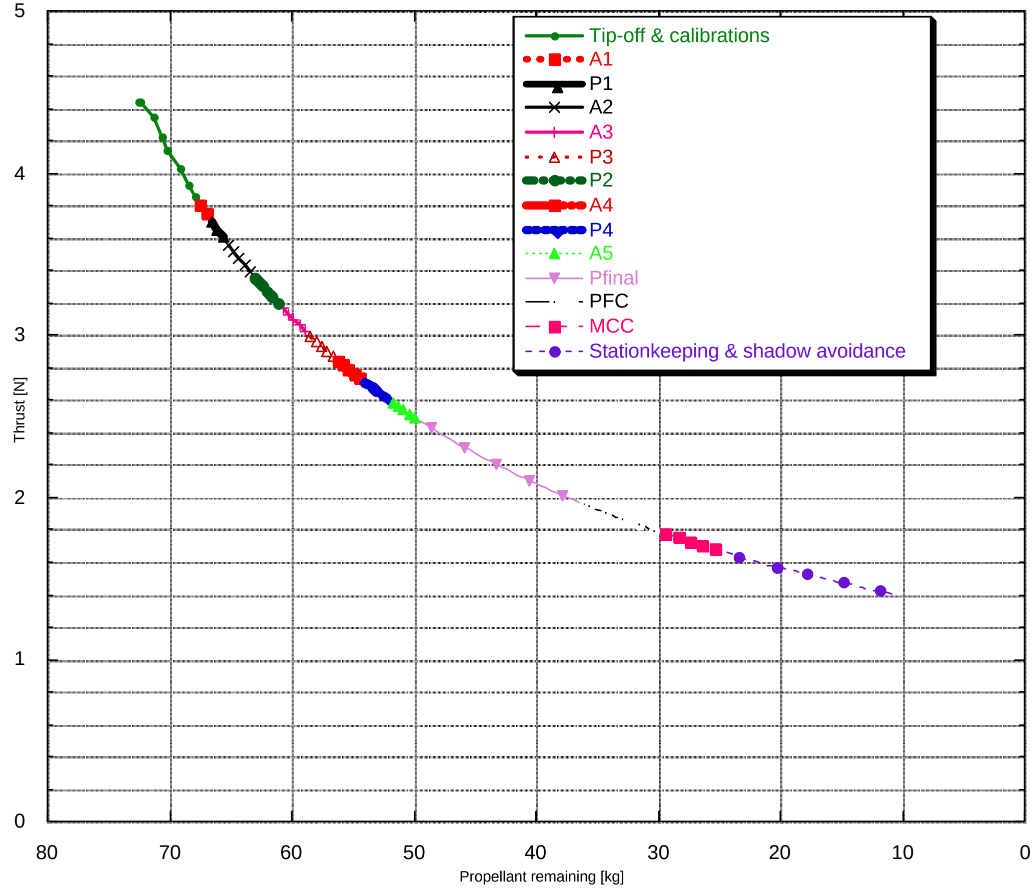
- Temperature telemetry:
  - 8 catalyst bed PRT's
  - 8 thruster valve thermistors
  - 2 thruster bracket thermistors
  - 10 propellant line thermistors
  - 1 fill & drain valve thermistor
  - 1 thermistor on HXCM (filter, isolation valve, pressure transducer)
  - 2 thermistors on propellant tank
- Pressure telemetry via pressure transducer
- Isolation valve position indication
- Power status:
  - ON/OFF for primary, redundant, catbed heater circuits
  - ON/OFF for boxes, EVD power, valve drive power, etc.
- Post-maneuver fuel calculation (counts) & pressure

Operations / Catbeds

- Thruster catalyst beds need to be heated before use
  - Each thruster has a primary and redundant heater element
  - Catalyst bed telemetry is NOT redundant
    - At this time, only the MAC box can read catbed temperatures
    - A software change request is being looked-at to see if the PRT temperatures can be read with the redundant LMAC box
- Catalyst beds should be at 125 °C before firing
  - Heating the catbeds should take approx. 30 minutes at the worst case low voltage and worst case cold conditions
  - Actual catbed heater warm-up time will be determined during T/V
- Catalyst bed heaters remain ON during the maneuver
  - Keeps low duty cycle control thrusters warm and ready-to-fire

Operations / Thrust & Pressure

- Thrust will decrease during the mission
- Thrust level before maneuver is known via tank pressure; thrust changes shall be modeled in HiFi / HDS / Astrogator during maneuver simulations



Thermal Subsystem Operations

Kimberly Brown

Thermal Subsystem Overview

- **Instrument cold stage conductively isolated from s/c via gamma alumina cylinder to minimize heat transfer.**
- **No heater cycling during Science Observation Mode.**
  - **Instrument requirement to minimize noise and enhance instrument stability imposed on s/c thermal design.**
- **Desire to not operate battery, transponders, star trackers for mission life near hot end of "approved" operational range, effectively narrows allowable range.**
- **Electrically conductive coatings, surface charging requires outer layer electrical resistance $<10^9$ ohm/sq.**
- **Deployable sunshade and solar arrays shadow bus and instrument from sun in science observation mode.**

Thermal Operations - Heaters

- **Flight temperature limits defined for Operational and Survival Conditions for all flight thermistors (internal) and external.**
  - **Selected thermistors used to control operational heaters and supplemental/make-up heaters and selected thermistors used to monitor survival heaters.**
- **S/C Operational Heaters controlled by software thermostat settings and are not to cycle during science observation mode:**
  - **Battery**
  - **Propulsion System (op/trim):**

    Prop Tank, fuel lines, PTF, Fill and Drain Line, Thrusters, thruster brackets.
  - **DSSE.**

Thermal Operations - Heaters (cont.)

- **Cat Bed heaters elements for all 8 thruster valves are commanded on prior to thruster firing.**
- **Make-up/supplemental heaters:**
  - **XPDR1 (Overtemperature thermostats)**
  - **XPDR2 (Overtemperature thermostats)**

    For the transponder, one prime make-up heater and the other is a redundant make-up heater.
  - **PDU (commanded On/Off), only used if multiple radiometers failed.**
  - **RXB supplemental heater, only used if RXB operating temperature too cold in flight.**
- **Survival heaters (thermostatically controlled).**

Operational Activities

Description of Activities per Major Mission Phase:

- **On the Launch Pad prior to Launch:**
  - **Battery air-conditioning with battery air flow.**
  - **Critical temperature is battery temperature.**
  - **Monitor Instrument temperatures when Instrument powered on for extended periods for check-out, aliveness testing.**
  - **Operational heater and survival heaters enabled.**
  - **Command damper heaters on (thermostatically controlled) prior to launch.**
- **Launch and early orbit check-out:**
  - **Deployment of solar arrays - solar arrays, damper temperatures.**
  - **After solar array deployment and acquire the sun, damper heaters commanded off.**

Operational Activities

- **Launch and early orbit check-out:** (cont.)
  - **For Instrument unpowered duration (4 hours after launch) (survival temperature limits set) RXB, PDU, AEU/DEU and 2 thermistors mounted to Upper ring of GAC monitored. (only theses 5 HKRSN telemetry available for instrument) (survival heaters cycling for PDU and AEU/DEU).**
  - **When Instrument powered on - monitor cold amps, TRS, RXB, PDU and AEU/DEU telemetry temperatures.**
  - **For Star tracker unpowered, external thermistor mounted on housing monitored.**
  - **When Star tracker powered On - monitor CCD, TEC, lens, housing temperatures.**
  - **All other electronic components thermistors temperatures monitored and operational limits set.**

Operational Activities

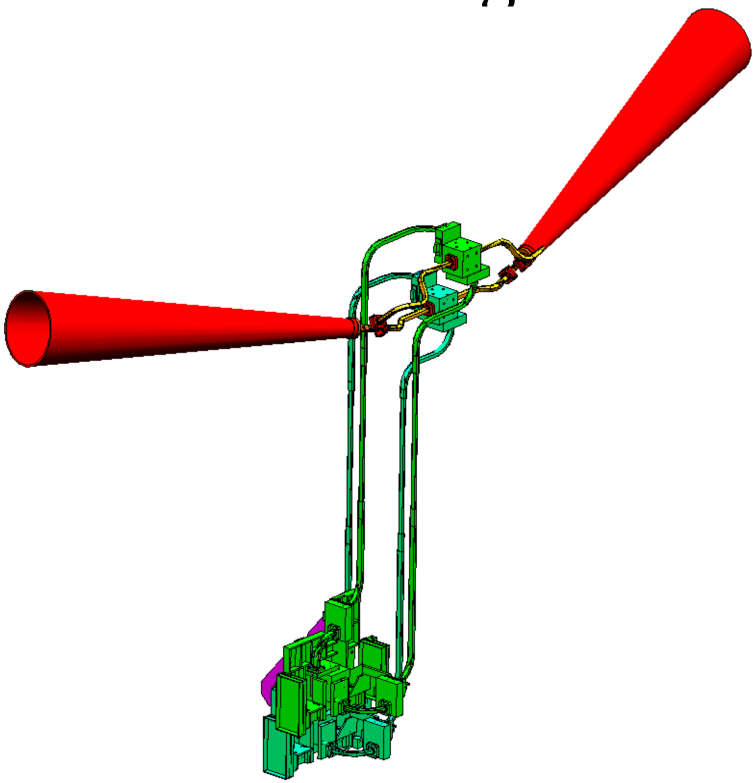
- **Lunar Phasing Loop Maneuvers, cruise to L2, monitor temperatures.**
- **L2 acquired - Science observation mode (will correlate flight thermal model with L2 flight temperature data).**
- **All mission phases**
  - **The Xponder make-up heater is used throughout all phases of the mission to maintain constant power and constant temperature balance while the Xponder is not transmitting.**
    - **Xponder make-up heater is cycled on when Xponder transmitter is cycled off (and vice-versa).**

Overview of Health Monitoring and Trending

- **Monitor components temperatures:**
  - **Battery, propulsion tank, fuel lines, thrusters, IRUs, RWs, RWEs, RXB, cold amps, PDU, AEU/DEU, MAC, LMAC, PSE and Star trackers, VRAIL, Transponders.**
- **Can change thermostat set-points for operational heaters in software system if required due to a thermal concern.**
- **Command Make-up/supplemental heater for PDU, RXB.**
  - **PDU make-up heater used if multiple radiometers failed.**
  - **RXB supplemental heater commanded on if RXB on-orbit temperature colder than predicted.**
- **Plot Temperature Trend Data:**
  - **cold amps, reflectors, Battery, solar arrays, IRUs, RWs, RWEs, Star trackers, RXB, PDU, PSE, AEU/DEU, MAC, LMAC, thrusters, prop tank, fuel lines.**
- **Monitor Instrument temperature stability, particularly on spin period time scale at science observation mode.**

MAP Instrument Operations

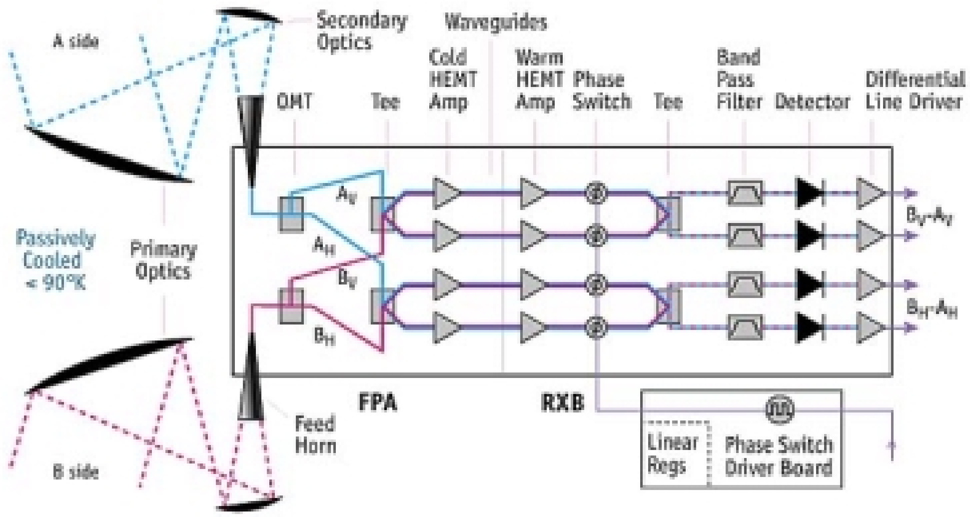
Alan Kogut



990079 MAP differencing assembly - Phase A Design MAP-MMEDIA-54

MAP Instrument Operations

- Pull faint signal from a sea of noise
- Critical to avoid instrumental artifacts
- Environmental stability is last line of defense



In-Orbit Checkout Activities

- Commands
  - Verify Instrument command link.
  - Adjust the bias voltages if required (V11)

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- Telemetry
  - Verify receipt of all Instrument Telemetry packets.
  - Limit Checking.
  - Decompression Verification

Instrument Activities during Flight Operations

Daily Activities/Periodic Activities

- Commands
  - None (spin and stare operations)

- Telemetry
  - Limit Checking
  - Data Trending of Instrument Housekeeping Telemetry
  - Decompression Verification

Health Monitoring/Trending

Health and Safety Monitoring

- Limit Checking
  - Drain Currents
  - Converter Voltages
  - RF Bias
  - Temperatures
  - Housekeeping Status Bits/Error Words
- Science data checksum verification after decompression.

Trending

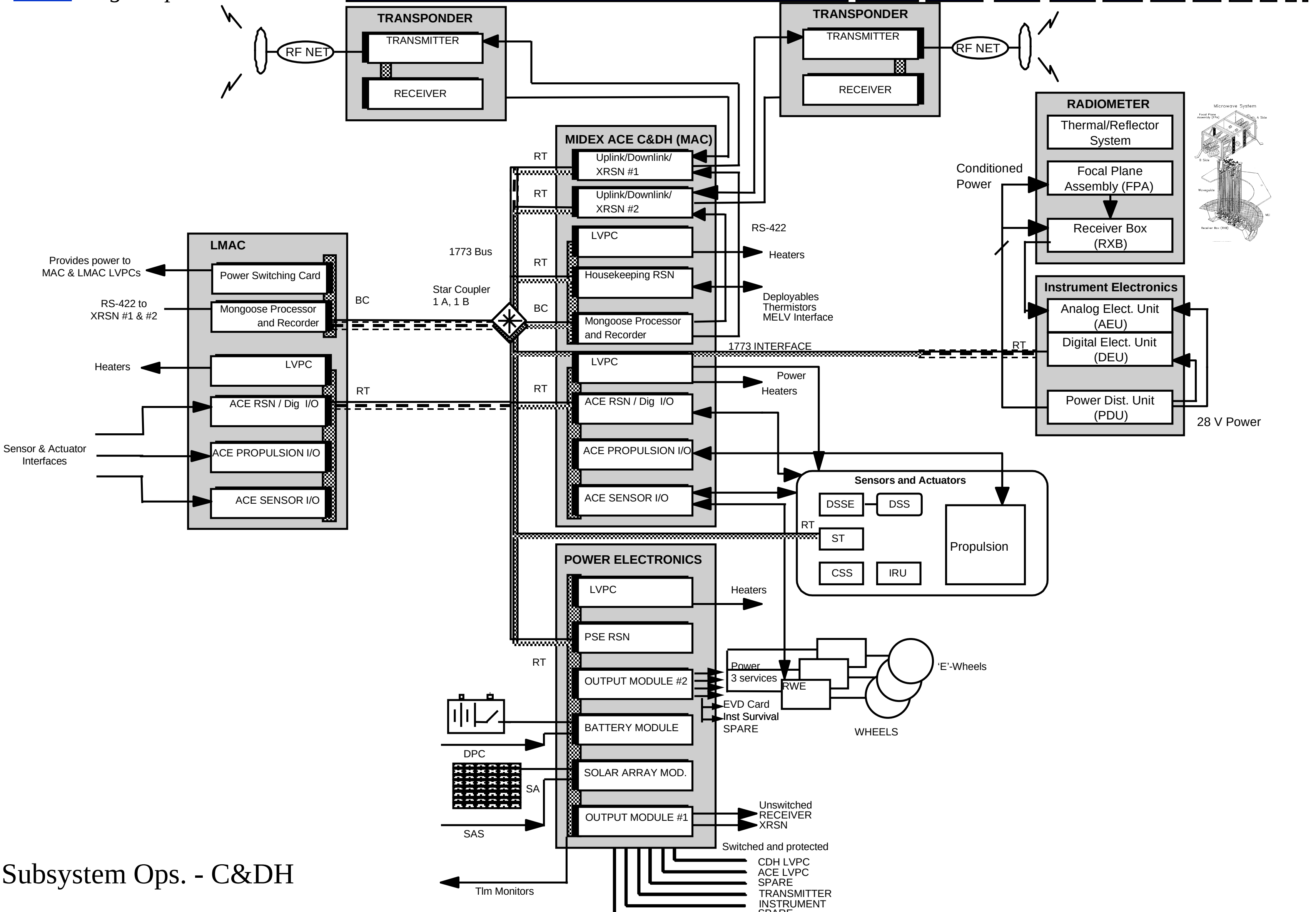
- All of the above
- Additional trending (+ science data) from OMEGA team

Command & Data Handling Subsystem Operations

Jack McCabe

C&DH in a Distributed Architecture

Flight Operations Review



MV Operational

- MV
  - **Single Mongoose V 32-bit Rad-Hard RISC Processor**
    - R2000/R3000 Instruction Set Compatible CPU(LSI Logic LR33000 Core)
  - **4MBytes of Jumper Configurable (64KByte steps) EEPROM (1Mx32)**
    - Write-Protected Bootstrap Region, Boot Region, Flight-Writeable Region
  - **1773 Bus Controller Shared Memory Interface**
    - Based on HST & Landsat 7 ASSR Processor Implementation
  - **256MBytes ofDRAM**
    - 256 Mbytes (4Mx32) of Data Storage, 64 Mbytes (64Mx8) of EDAC
  - **Spacecraft Time Keeper**
    - 32-bit Seconds Counter,22-bit Microseconds Counter,Reset on power cycling only
  - **Watchdog Timer**
    - 16-bit interval timer clocked at 16Hz (62.5ms resolution)
    - Generates software reset upon timeout unless WD timer is re-loaded
  - **External Timer**
    - 16-bit interval timer clocked at 60KHz (16.6us resolution)
  - **Serial Output port to XRSN**
    - Selectable from 1, 2, 4, & 8 Mhz data rates
  - **External Waitstate Generators**

RSN Operational

- HKRSN
  - Active/Passive Analog
  - Separation Status
  - NED Command
  - RF Switch command
- XRSN
  - Selectable RATES and ENCODING, based mission phase
  - CCSDS Command and Telemetry protocol
  - Supports 37.5 minute dump of full day of HK& science data
  - Eight Special commands, decoded in hardware
- ACE
  - Provides independent safe hold capability
  - Attitude Control Interfaces for:
    - Course Sun Sensors & Digital Sun Sensors
    - Inertial Reference Unit
    - Reaction Wheels
    - Propulsion System

Planned Operations Activities

- **Daily Activity**
  - Clock Correlation
  - S/C and ACS processor control
- **Periodic Activity**
  - Deployment
  - HKRSN Auto Heater Cycling
  - XRSN Selection (Based on Mission Timeline)
  - XRSN Configuration (Based on Mission Timeline)

Spacecraft Clock Maintenance

- Clock Maintenance Requirement (Ground vs. Spacecraft) : ± 1 second
- Adjustments to S/C time are made by adjusting UTCF
  - Large clock adjust made by loading new UTCF
  - Clock adjust < ±2 milliseconds by using UTCF adjust command
  - Leap second adjust via leap second adjust command
  - Once oscillator drift is characterized, the 1hz auto adjust UTCF command will be used to compensate for the drift

XRSN Configuration

- XRSN Configuration (Based on Mission Timeline)
  - Supports 2K-1.5M Downlink base rate
  - Supports downlink encoding options:

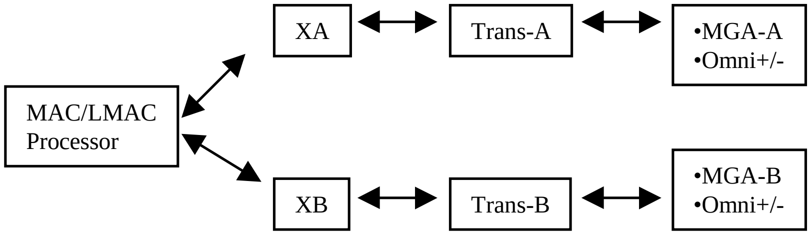
    Reed Solomon

    1/2 or 1/4 Convolutional

    Pseudo-Randomization
  - Onboard FSW table in XRSN contains Rate/Encoding configuration which will be commanded based on mission phase.

- XRSN Selection

  (Based on Mission Timeline)



C&DH Health Monitoring

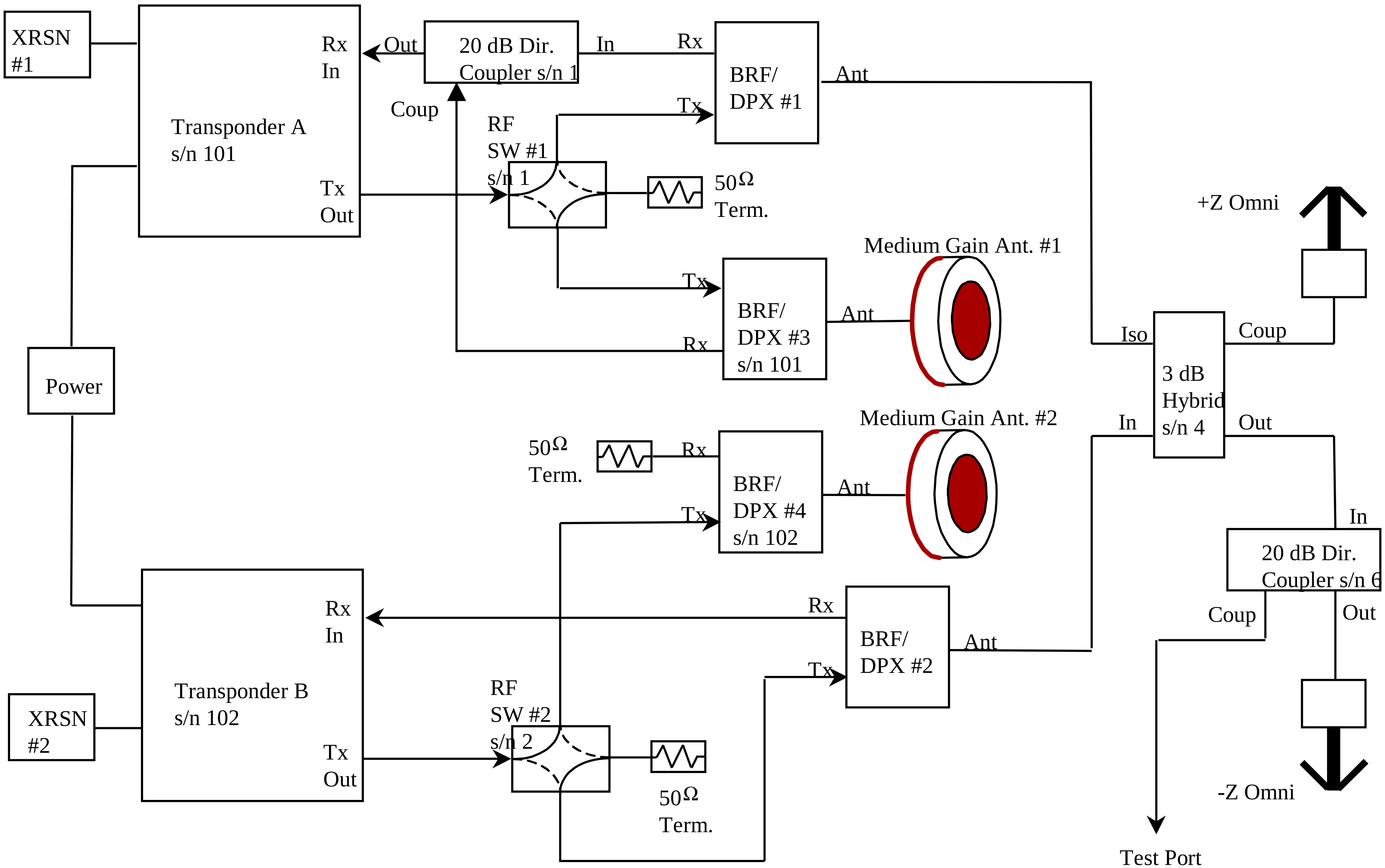
- EDAC & Memory Scrub
  - Single Bit Correction/Multi Bit Detection
  - Full Scrub Cycle every 30 - 45 mins.
- 1773 Retries and Errors
- Deployment Status
- Card Level Trend Data
  - Voltages
  - Temperatures
  - Currents

RF Subsystem Operations

Mike Powers

MAP RF Block Diagram

Flight Operations Review



Communications Configuration

- L&IOC Nominal Configuration:
  - Command Link:

    DSN → Omni → Transponder-A → XRSN-A → Mongoose V
  - Telemetry Link:

    Mongoose V → XRSN-A → Transponder-A → Omni → DSN

- Mission Nominal Configuration:
  - Command Link:

    DSN → Omni → Transponder-B → XRSN-B → Mongoose V
  - Telemetry Link:

    Mongoose V → XRSN-B → Transponder-B → MGA-2 → DSN

Transponder Operations

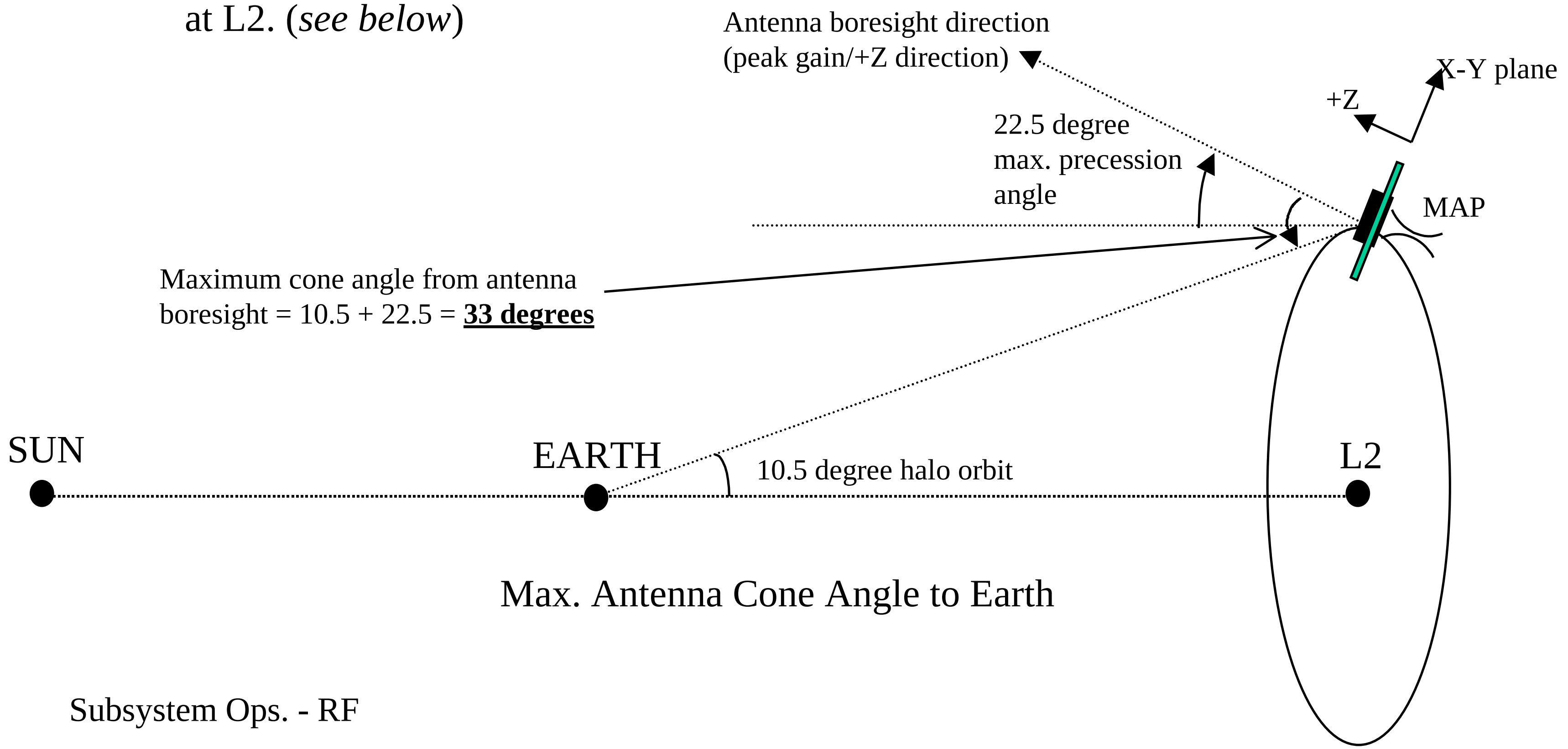
- Transponder Modes
  - Coherent: Downlink frequency derived as a ratio 240/221 of the uplink frequency.
  - Noncoherent (Aux. Osc. ON): Downlink frequency derived from crystal oscillator in transmitter
  - Ranging Channel ON: Uplink modulation (ranging signals) is received and remodulated on the downlink carrier. Nominal configuration during passes.
  - Ranging Channel OFF: No uplink modulation is remodulated on downlink.

Transponder Operations

- Transponder Commands Used on a Daily Basis
  - Receiver
    - No commands-Receiver is powered via unswitched service
  - Transmitter
    - Transmitter ON (beginning of pass)
    - Transmitter OFF (end of pass)
    - Ranging ON (beginning of pass)
    - Ranging OFF (end of pass)
- Other Commands
  - Transmitter
    - Auxiliary Oscillator ON (Standby/Emergency Ops.)-forces noncoherent mode

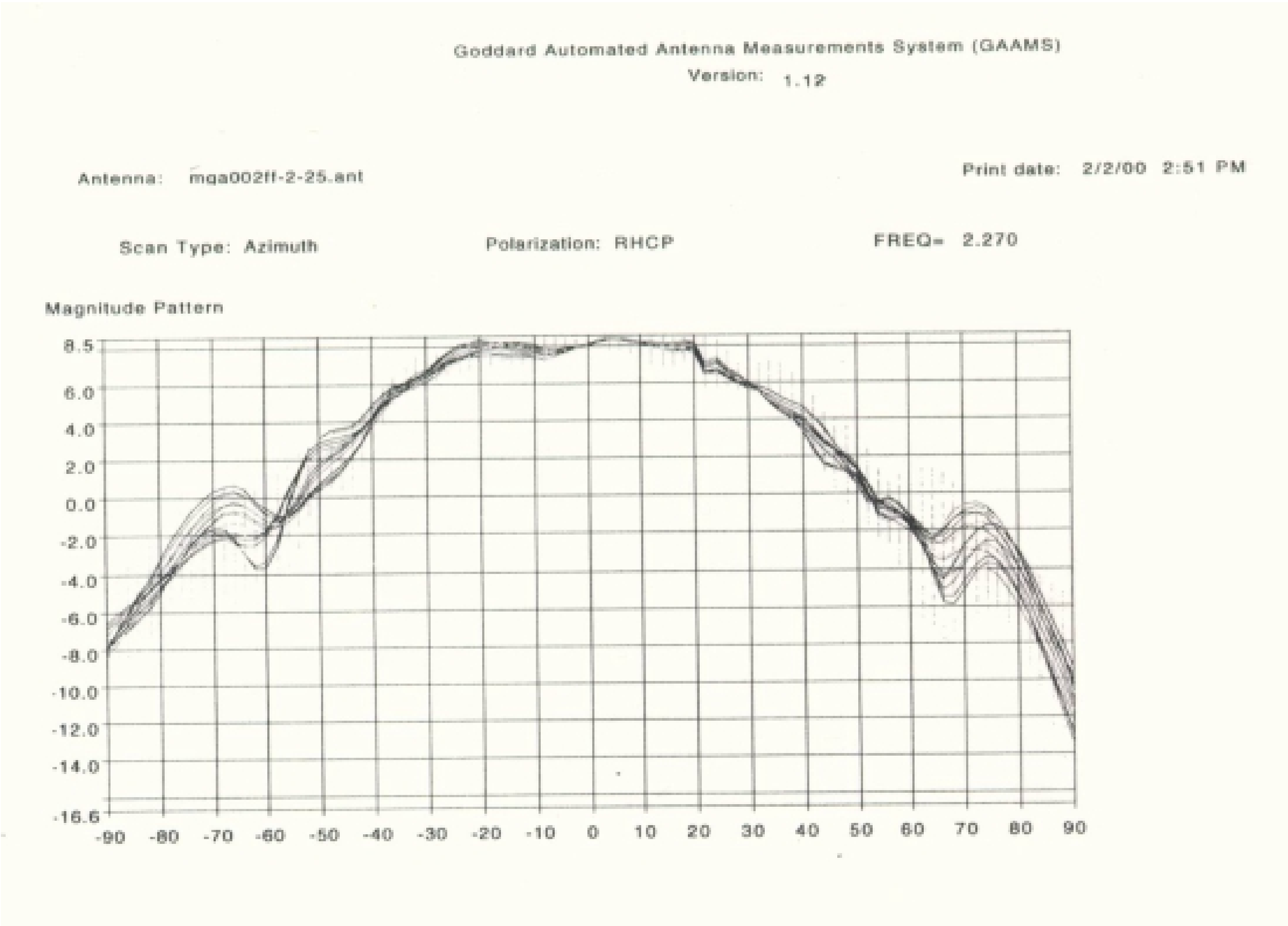
Antenna Operations

- RF Antenna Modes
  - Omni-directional antenna used at launch and during early mission
  - During cruise phase (after lunar swingby) transition to MGA-2 for primary downlink
  - MGA beamwith (>5.0 dBi gain ±33° off boresight) is required to support high rate communications while the spacecraft is in science observing mode at L2. (*see below*)

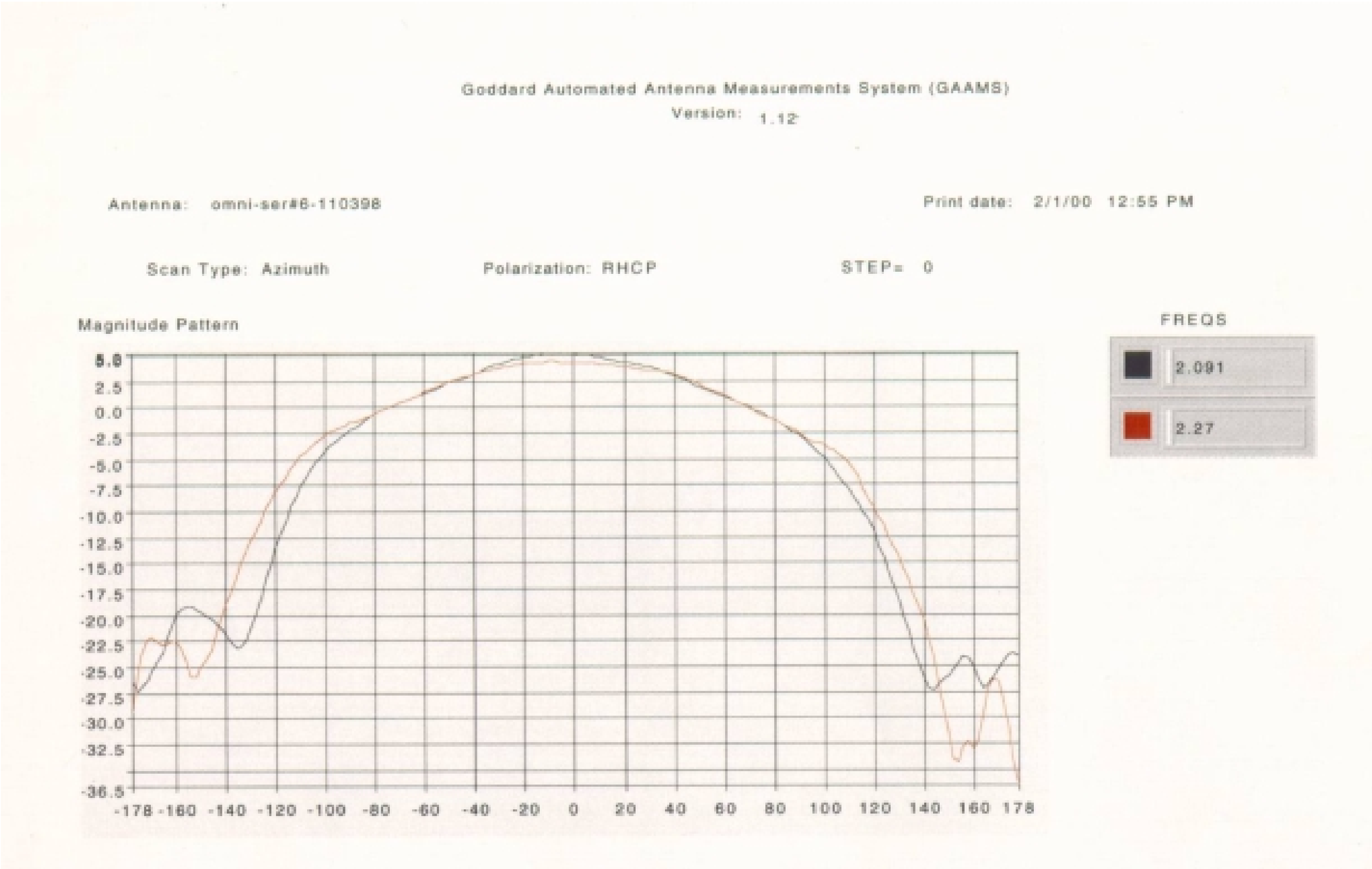


Max. Antenna Cone Angle to Earth

MGA B Gain Pattern



Omni Gain Pattern



Link Margin vs Mission Phase

Comm. Link/Distance from Earth	Baseline Data Rate (kbps)	Coding	Link Margin (dB)	Mission Phase / Comments
34BWG to Hemi Omni/ 1000 to 3.84E+5 km.	2.0	N/A	64 to 12.4	Primary uplink for phasing orbits to lunar swingby. Assumes a 1 kW transmitter
70 m. to Hemi Omni/ 3.84E+5 km. to 1.55E+6 km.	2.0	N/A	41 to 28.6	Primary uplink from lunar swingby to L_2 halo orbit
34BWG to Hemi Omni/ 1.55E+6 km.	2.0	N/A	19.4 to 7.3	Backup uplink from lunar swingby to L_2 halo orbit Assumes a 5 kW transmitter
Hemi Omni to 34BWG downlink/ 1000 to 3.84E+5 km.	100	Rate 1/2, K=7 + R/S	55 to 3.8	Primary downlink for phasing orbits to lunar swingby
Hemi Omni to 70 m./ 3.84E+5 to 7.5E+5 km.	222	Rate 1/4, K=15 + R/S	9.2 to 3.4	Primary downlink from lunar swingby to 6 days after lunar swingby
Med. Gain to 70 m./ 7.5E+5 to 1.55E+6 km.	666	Rate 1/4, K=15 + R/S	9.3 to 3.0	Primary downlink from 6 days after lunar swingby to L_2 halo orbit
Med. Gain to 34 m./ 1.55E+6 km.	120	Rate 1/4, K=15 + R/S	3.2	Backup downlink mode at L_2
Omni to 34 m./ 1.55E+6 km.	6.2	Rate 1/2, K=7 + R/S	3.8	Emergency downlink mode at L_2

<u>Assumptions</u>:

- •JPL's CCSDS Link Design Control Table used for all analyses.
- •BER = 1E-8
- •Mod Index = 1.40 rad-pk
- •Ant. Pointing Loss = -0.2 dB
- •DSN Block V Receiver

RF Health Monitoring

- Transponder Telemetry Limits and Trending Parameters
  - Receiver input power (AGC)
  - Transmitter output power
  - Receiver Static Phase Error (SPE)
  - Receiver & Transmitter 20V converters
  - Temperatures
    - Transmitter power supply
    - RF Amplifier
    - Transponder baseplate

Power System Flight Operations

Bob Wingard

Power System on MAP Structure

6 Identical Solar Array Panels

GaAs/Ge cells EOL (496 watts)

Nickel Hydrogen Battery

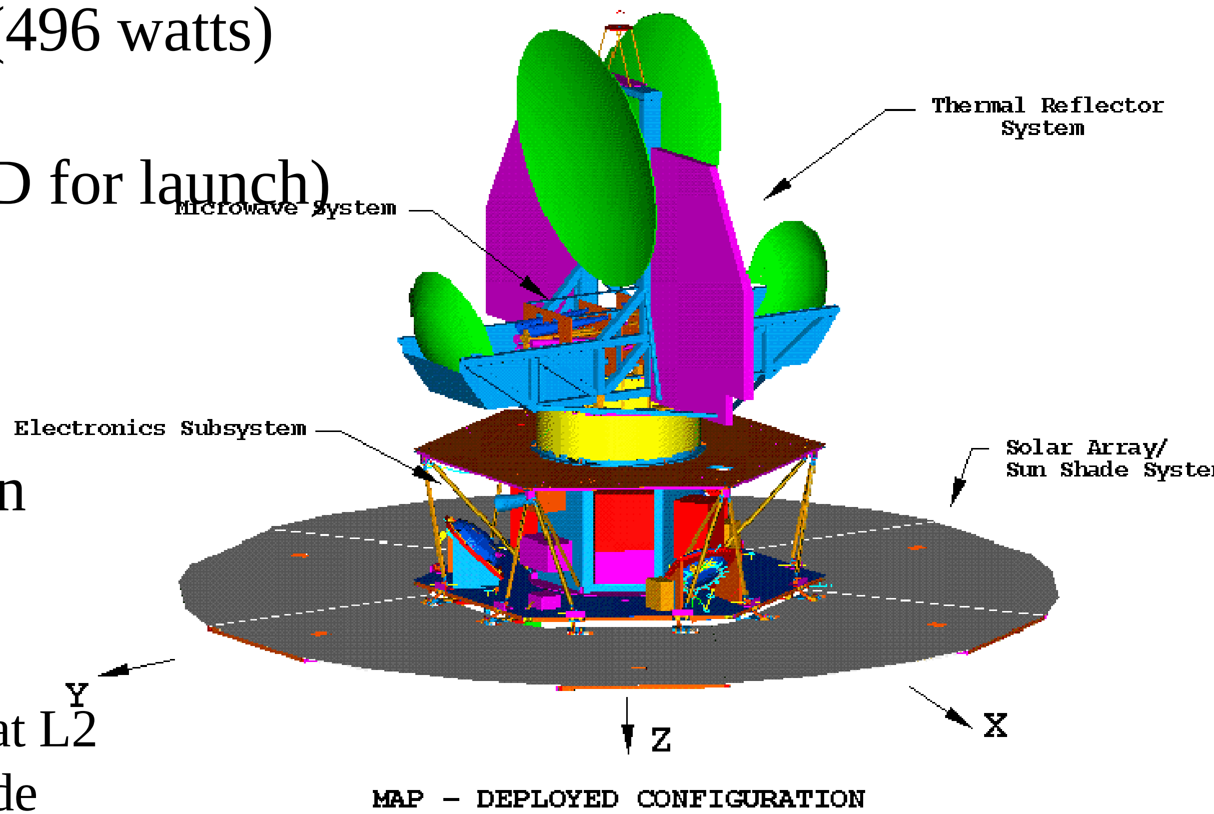
23 Amp-hr (49% DOD for launch)

PSE

Power Regulation

Charge Control

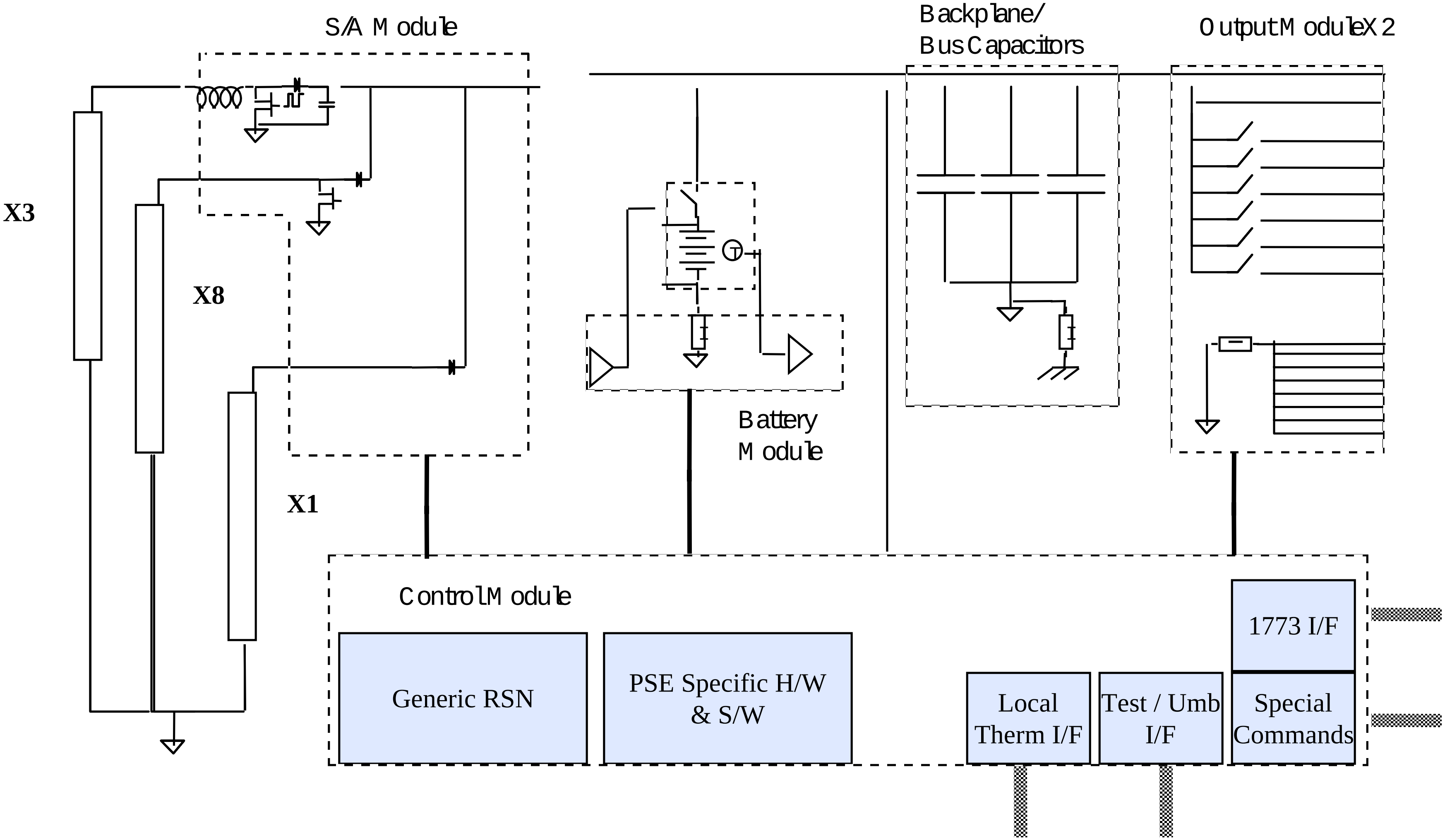
Switching/Distribution



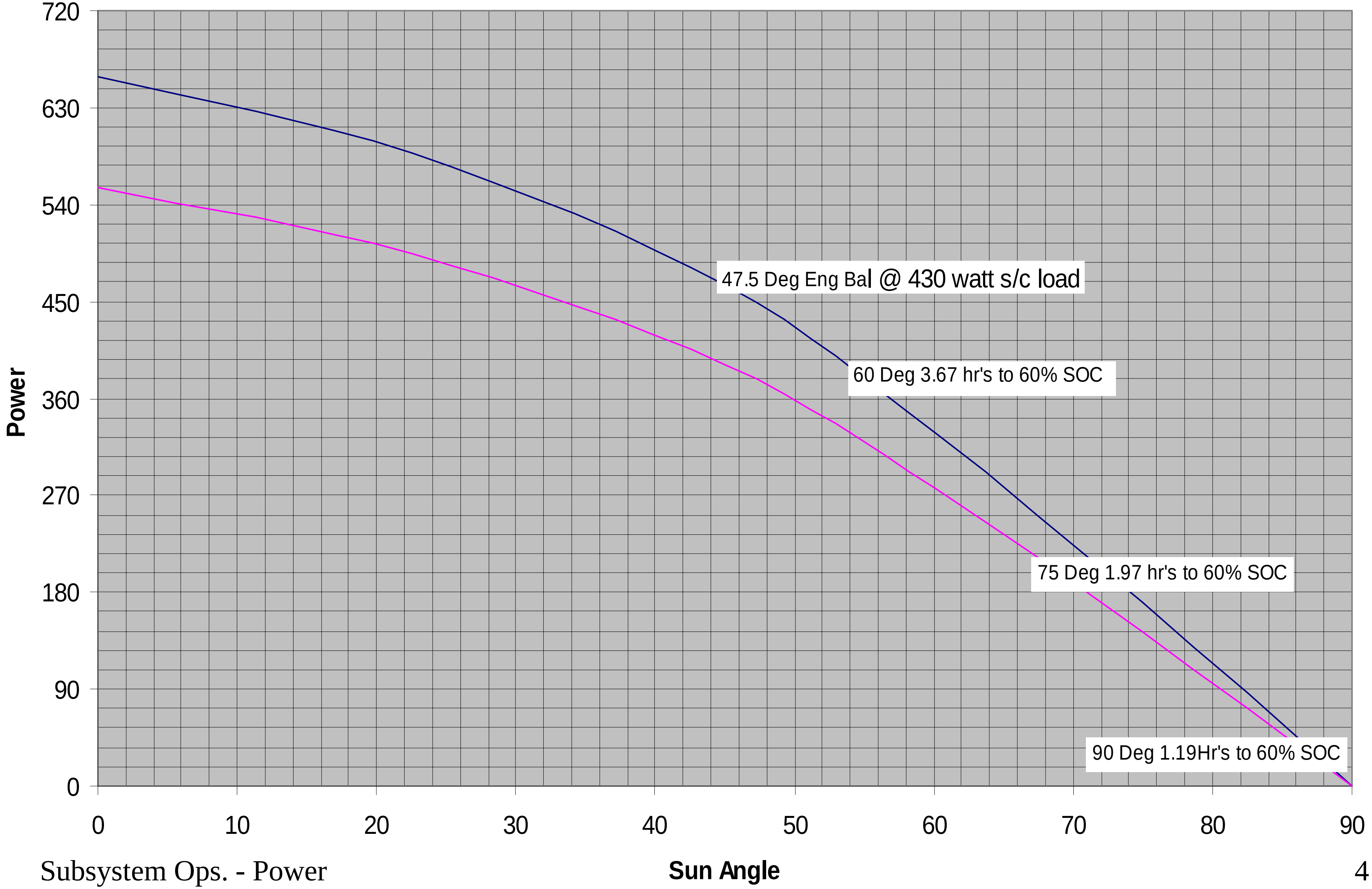
- S/C Bus Load
  - 420W Orbital Average at L2
  - 457W in Maneuver Mode
  - 420W in Safehold
  - 245W in TMS Load shed

Power Subsystem Block Diagram

Flight Operations Review

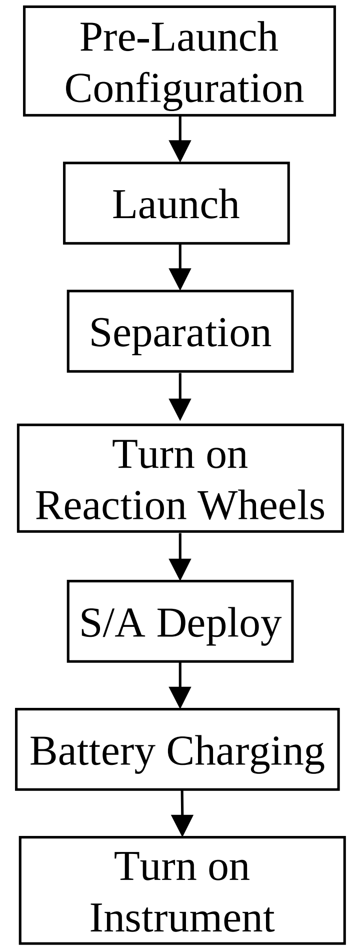


Sun Angle to S/A Power



Operational Activities

Normal Operations Flow



Normal Operations

- Normal operation of the MAP Power Subsystem is fundamentally autonomous
  - Load Management
  - Charge Control
  - Health Monitoring

Operational Activities

- **Pre-launch**
  - Start RTS 150 - loads and starts PSE timer for backup Reaction wheel power up
  - All PSE LVPC services switched ON
    - LVPC service 2 (Battery operational heater) is software controlled
- **Post-launch Load Management**
  - Reaction Wheel Power (SSPC 7,8,9) switched at Separation via TSM / RTS
  - Instrument Power (SSPC 1) switched after the S/C is power positive and stable on the sunline

Operational Modes

- **Charge Control Modes**

  Flight Software controls the Battery charge current. Regulates the PWM and controls the Solar Array Segments.

  - Current Control - High Rate Charge

    Commanded - 9 Amp Default

  - V/T Taper Charge

    12 Commanded V/T levels - V/T 5 Default

    Bus V = 32.12 @ 0 c

    Flight V/T level - TBD - post Thermal Vac

  - Trickle Charge

    Commanded trickle charge rate - .23 Amp Default

    Flight trickle charge rate - TBD - post Thermal Vac

Power Subsystem
Health Monitoring / Trending

Flight Operations Review

- Health Monitoring (Ground)
  - Use of tight Asist limits
    Bus voltage, BSOC, Bat Voltage, Bat Pressure, Bat Temp
  - Over 150 PSE telemetry points are limit checked
- Health Monitoring (Onboard)
  - Telemetry Statistics Monitor (TSM)
    Bus Voltage, Low Battery Capacity, Battery Differential Voltage, Battery pressure, Bat temperature
  - Fault Detection and Correction (FDC)
    Switch Monitor, BSOC, Bat V, Bat Pressure, BatTemp
- Trending
  - Battery telemetry, - (V, I, Temp, SOC, Pressure, Differential V)
    Solar Array telemetry - (I, Temp)
    Secondary Voltages (+5, +15, -15)
    Current Shunts

Periodic Activities

- **Battery Maintenance**

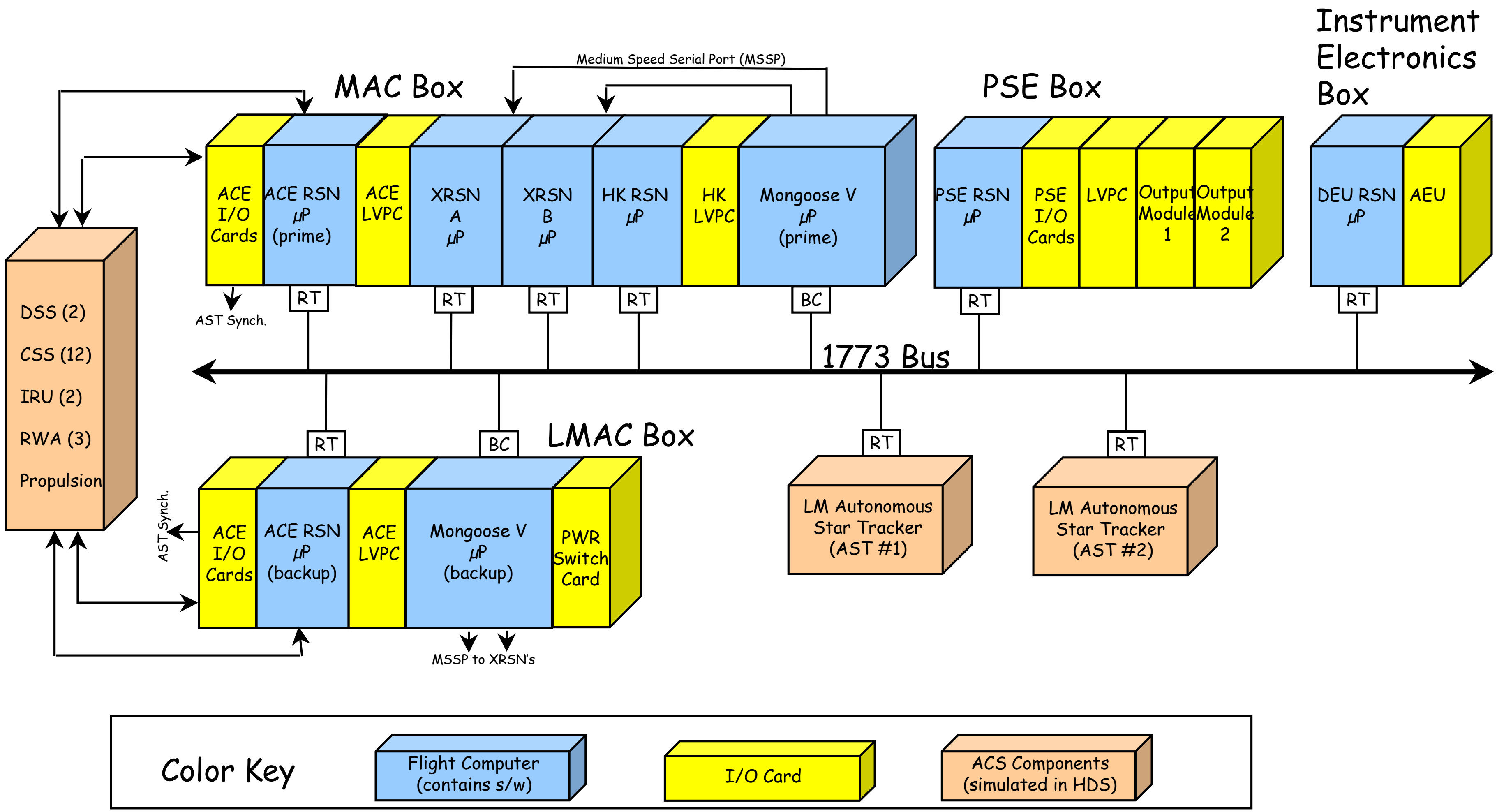
Based on review of operational and trending analysis some parameters may need to be adjusted to maintain optimal battery performance:

- Command new V/T level
- Command new Trickle charge rate

Flight Software Operations

Jane Marquart

Flight Software
Overview/Software Context



Flight Software Overview

- Mongoose V software functions include:
  - Solid State Recorder control
  - Attitude Control Software
  - 1773 bus control
  - Table/Memory operations
  - Telemetry & Statistics monitoring
  - Health & Safety monitoring

- Remote Service Nodes (RSN) software functions include:
  - Application specific operations
  - Memory operations
  - Health & Safety monitoring

Flight Software Operations

- Daily Operations Activities
  - Solid State Recorder (SSR) Playback (M-V)

- Periodic Operations Activities
  - Table Operations (M-V)
    - System Tables
    - Stored Command Tables
      - Absolute Time Sequence (ATS)
      - Relative Time Sequence (RTS)

Solid State Recorder Operations

- Scheduled 37 minute pass daily. Recorder sized for 2 days
- Daily dumps done @ 666Kb downlink rate; est. ~ 23minutes (1 day's worth of data)
- SSR memory divided into 3 Virtual Recorders (VR's)
  - VR#1 Spacecraft & Instrument Housekeeping 100Mb
  - VR#2 Spacecraft Events 85Kb
  - VR#3 Science 130Mb
- VR#1 & #2 operate in non-overwrite mode; VR#3 operates in overwrite mode
- Default priority of recorders from highest to lowest is VR#1, VR#2, VR#3
- VR's are defined by an onboard segment table and are modifiable in flight via a software table load.
- The CCSDS packet storage filter factors are configurable in an onboard system table.

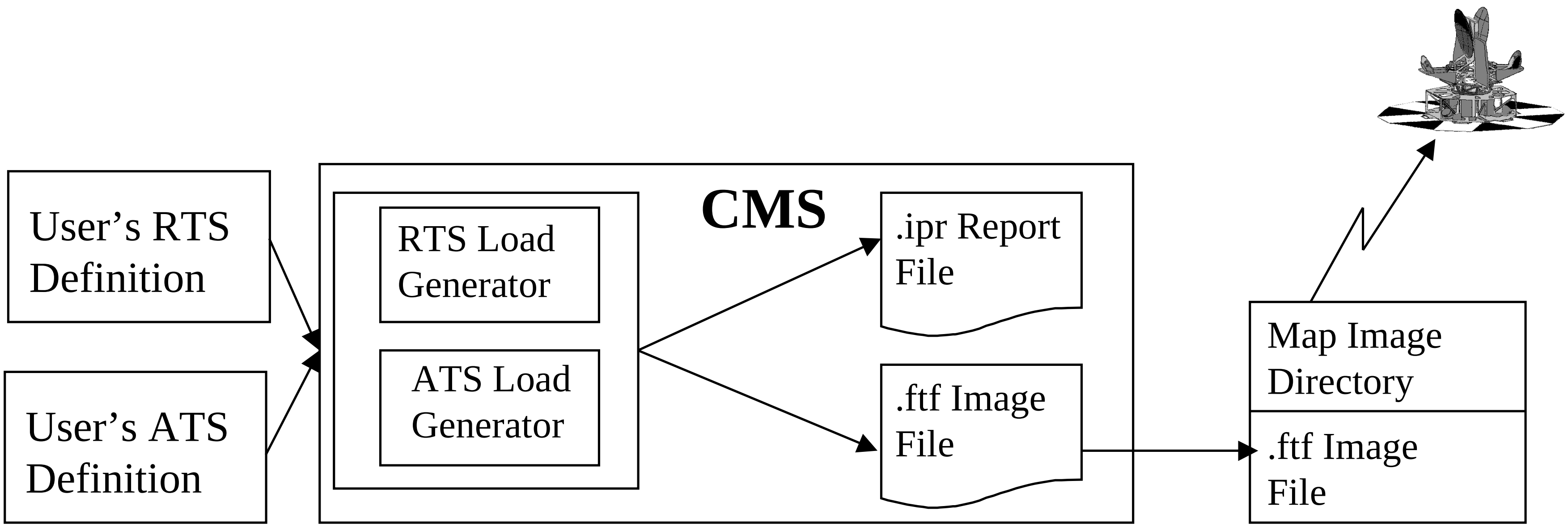
Table Operations

- Loading a Table:
  - Select system/stored command table
    - Initiates table session and session constraints
    - Command parameters
      - Table ID
      - From Image (EEPROM, RAM, Null)
      - Session Type (Dump only, Replace EEPROM, Replace RAM, *Append Active[SC tables only]*)
  - Load data table (up to 100 words to specified offset)
  - Commit table (with number of words loaded)
    - Coordinates with Checksum Task
    - Coordinates with table owner task if table is NOT jam loadable (timeout for response)

Table Operations

- Dump table
    - 100 words/pkt, 65535 words per command
    - Initiates dump handshake with TO task
- Reset table operations
    - Terminates table session
    - All working buffer data cleared

Stored Command Management



- User defines RTS/ATS
- Using CMS, the user creates RTS/ATS
- CMS generates a report file and an image file
- The image file (.ftf) is copied to the /image directory
- The RTS/ATS is uploaded to the spacecraft by the user

Stored Command Management

- **Relative Time Sequences (RTS)**
  - Support routine S/C Functions and Emergency S/C safing operations
  - Initiated by TSM, ground command, or other RTS/ATS
  - 256 buffers, 300 bytes each
  - 45 defined
  - Nominally enabled/disabled by procedure based upon S/C configuration (I.e. launch, mission)

- **Absolute Time Sequences (ATS)**
  - Support time critical operations (i.e. Phasing Maneuvers)
  - Two sequences, up to 10000 bytes each
  - Only one active at a time

Flight Software Health Monitoring

Mongoose-V

- Checksums:
  - Boot prom
  - PROM
  - EEPROM
- Reset Telemetry
  - Cold and warm reset counters (mode transition log can be dumped for insight into resets)
- 1773 Bus errors/retries
- CPU utilization (trend data)

RSN Processors

- Checksums:
  - PROM
  - EEPROM
  - Instruction RAM
  - Static Data Areas (ACE only)
- Reset Telemetry
  - Cold & warm reset counters
  - Watchdog reset counter
- Flywheel status (no clock updates)

Reprogramming in Flight

Mongoose-V

- PROM cannot be modified in flight
- Permanent software patches can be stored in EEPROM
- Checksumming must be disabled when modifying code or tables

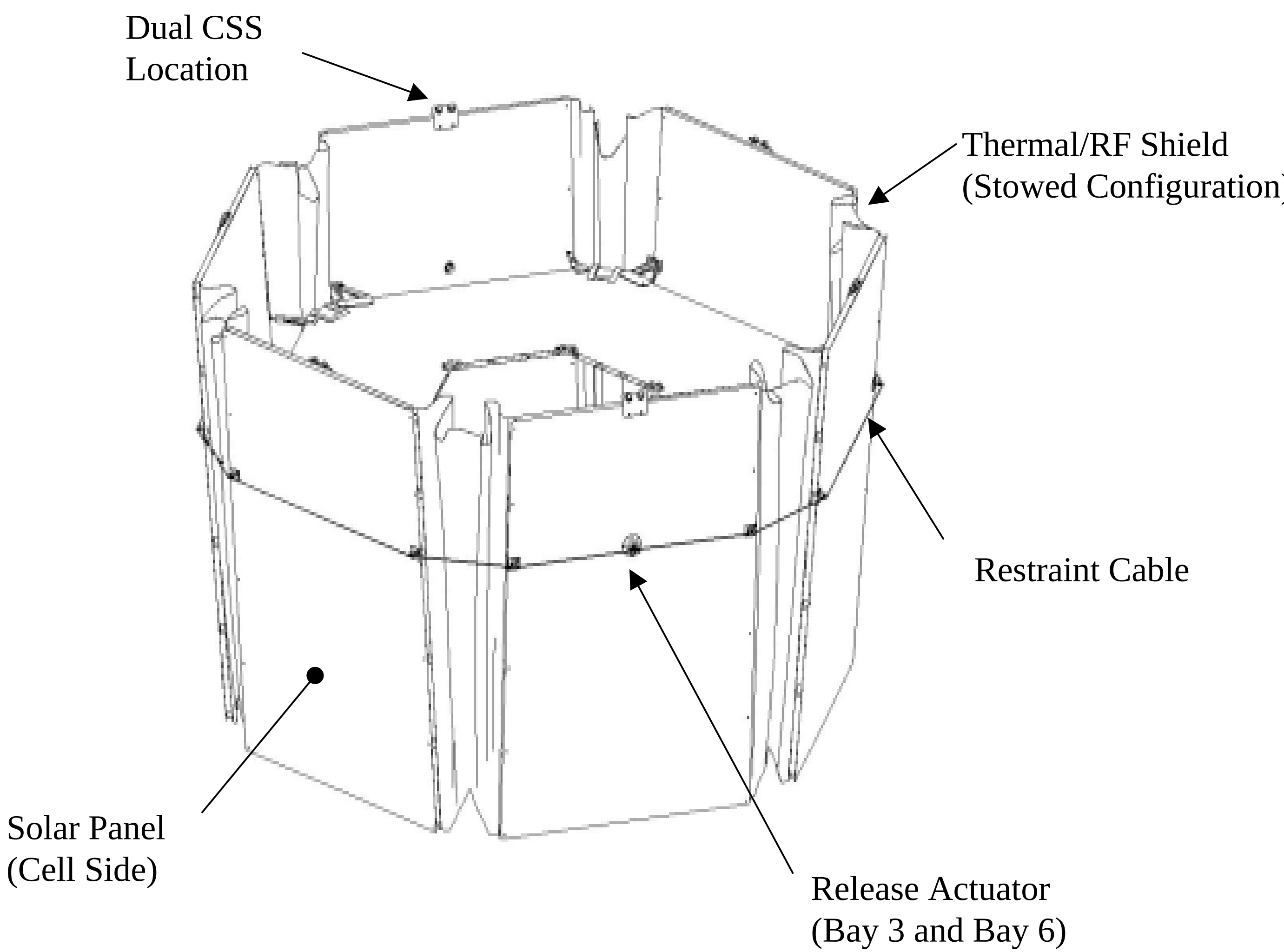
RSN Processors

- PROM and EEPROM cannot be modified in flight
- Permanent RSN software patches can be stored in the MAC and reloaded autonomously
- Checksumming must be disabled when modifying code or static data areas

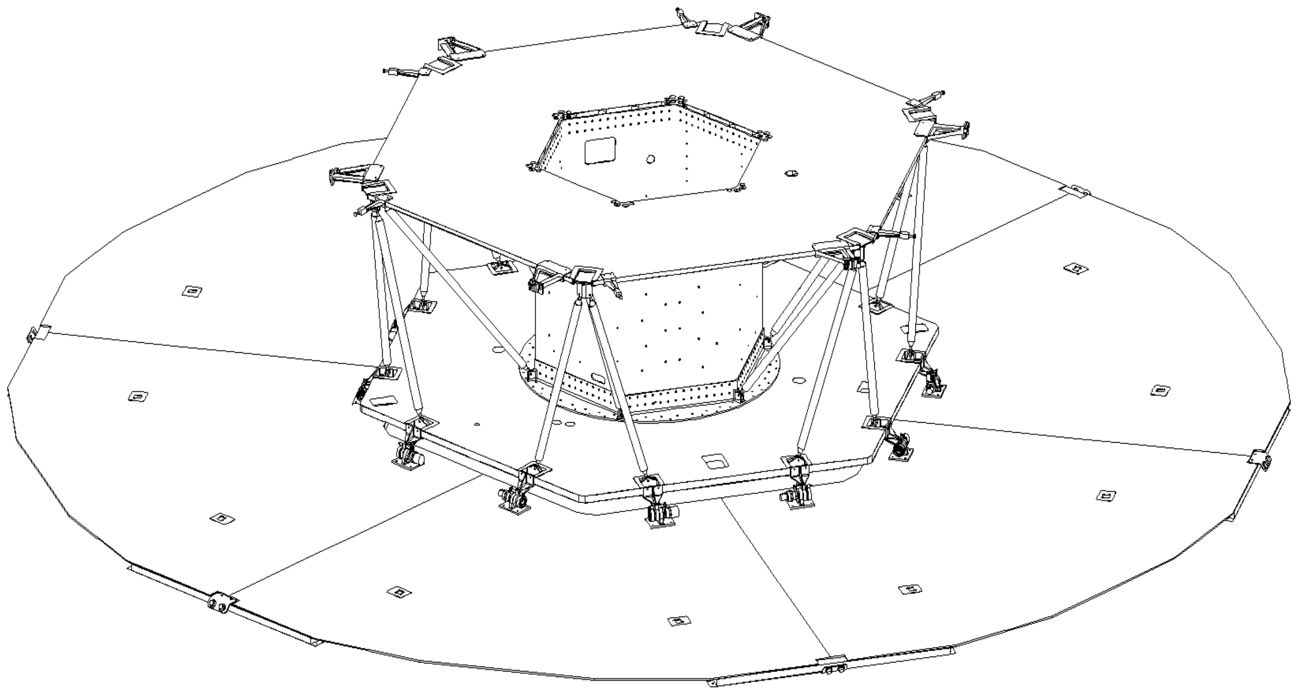
Solar Array Deployment System
Flight Operations

Alphonso Stewart

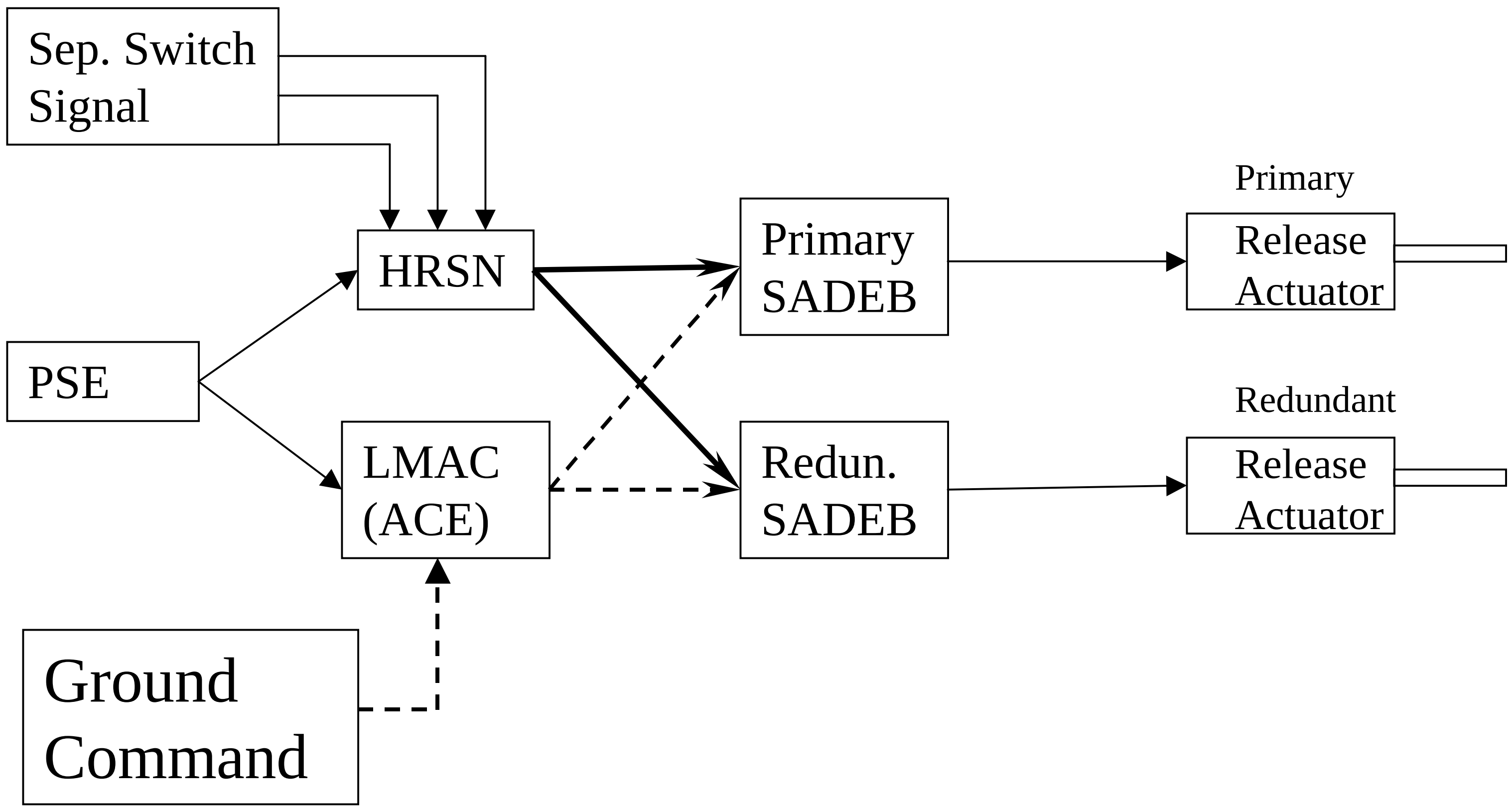
Solar Array Deployment System, Stowed



Solar Array Deployment System, Deployed



Deployment Actuation



Operation

- Prior to Launch
  - Verify arming plug
  - Verify damper heater power is enable

- Verify Separation & Initiating Deployment
  - <u>3 of 3</u> separation switch signal (power pri SADEB, 120 sec later power off pri SADEB and power on redun. SADEB for 120 sec.) *Autonomous Operation*
  - <u>2 of 3</u>, wait 120 sec and power redun. SADEB for 120 sec. *Autonomous Operation*
  - <u>1 of 3 or no signal</u>, wait for ground command to power pri. or redun. SADEB via HRSN or LMAC *(Power Switching Card)*

Operation, *continued*

- Verify Deployment
  - Potentiometer (Pri or redun.) indicates deployed angle.
  - Coarse Sun Sensor(css), changes in css current
  - Solar panel power profile (*no solar panel power for nominal spacecraft orientation prior to sun acquisition*)
  - Solar panel thermal profile (*Temperature decrease for nominal spacecraft orientation prior to sun acquisition*)
  - Changes in gyro rates
- Health and Monitoring
  - Power to damper heaters prior to separation (power off after deployment verification)
  - Damper temperature prior to and during deployment
  - SADEB voltage output
- No daily or periodic activities after deployment

MAP Ground System

Steven Coyle

Ruthless Efficiency

Project Requirements

13	**Science and Mission Operations**	
13.1	Real-time Commands	The ground system shall format and send real-time commands to the observatory.
13.2	Stored Commands	The ground system shall format and package stored commands for transmission to the observatory.
13.3	Real-time Telemetry	The ground system shall receive and display real-time telemetry from the observatory.
13.4	Playback of observatory telemetry	The ground system shall initiate and receive the playback of stored telemetry from the observatory and account for missing data.
	13.4.1	Missing data shall be identified prior to the completion of the ground contact period.
13.5	Memory Management	The ground system shall provide support for management of on-board tables and images.
13.6	Trending	The ground system shall trend observatory telemetry
13.7	Archiving	The ground system shall archive data upon receipt from the observatory.
13.8	Playback of Archived Data	The ground system shall provide the capability to playback archived data.
13.9	Orbit Products	Orbit products sufficient for science and mission planning shall be provided.

Ground System Requirements

- Requirements Documents
  - Combined Ground System Requirements Specification
    - Signed as of April 1997
  - DMR
    - All Requirements are in the DMR, and its been signed as of October 1999
- Completed DSN ICD's
  - TLM 3-29
    - Will Require MAP Supplement
  - CMD 4-9
  - Track 2-15A
  - Mon 5-15

Ground System Requirements

- TDRS RFICD
  - Signed as of November 1999
  - CCR to require command link in process
- Interface Control Document between the MAP SMOC and OMEGA
  - signed August 1999

DSN Requirements Summary

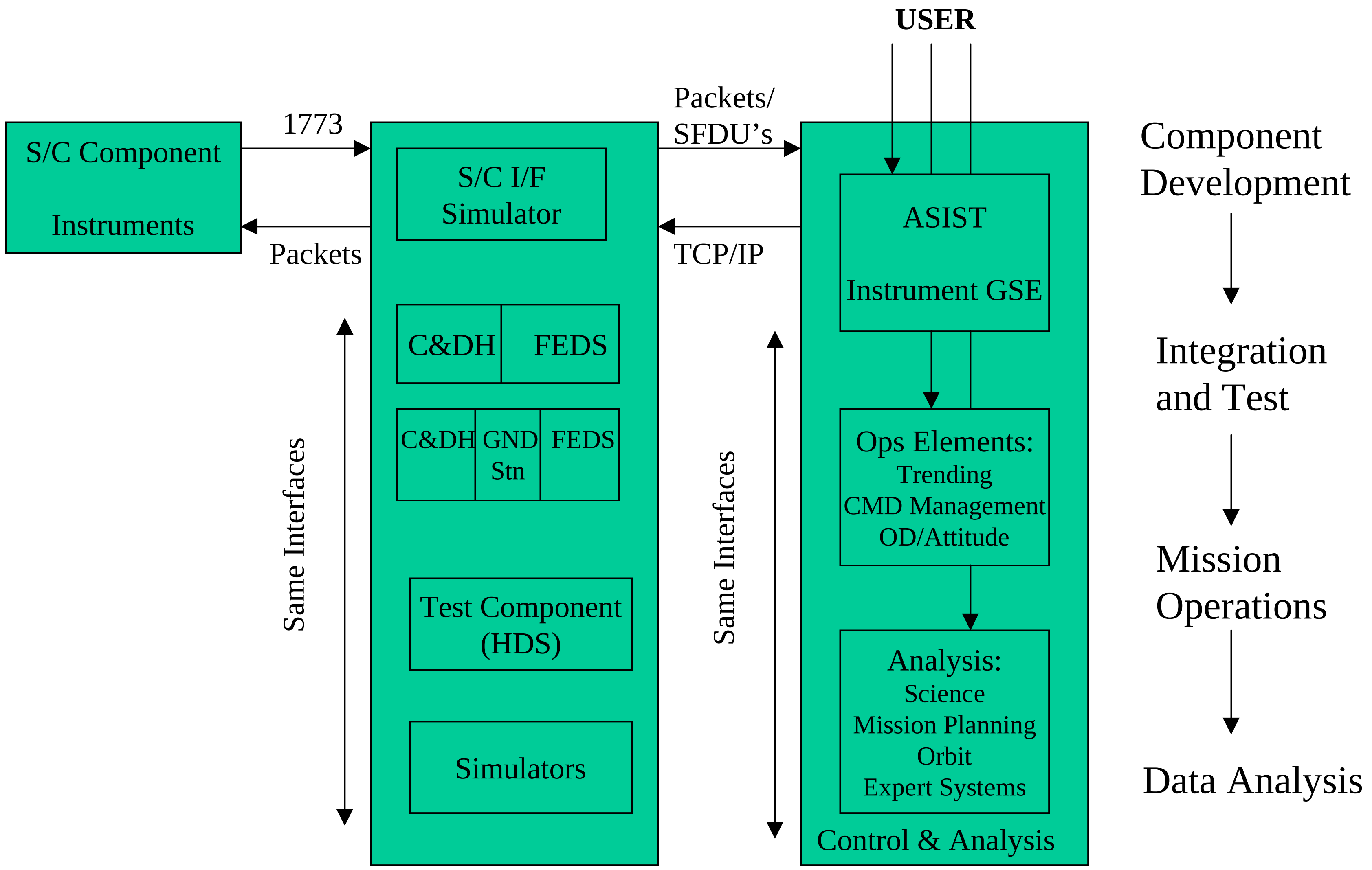
Mission Phase (In days)	Service	Passes/Day & Duration
Launch L+ 0 to L+ 1	Near-continuous support 26/34m with radio metric	2-station support first 12 hours Single station support second 12 hours
Lunar Phasing Loops L+ 1 to L+ 8	26/34m with radio metric	3-4 supports totaling 12 hours in duration Min.3 hours/support and 9 hours prime shift
L+ 9 to MCC	26/34m with radio metric through lunar fly-by	2-3 supports totaling 6-8 hours in duration
MCC	26/34m with radio metric through lunar fly-by	Minimum 2 hours/support
Perigee Burns and Lunar Fly-by	26/34m radio metric – near-continuous	Minimum 4 hours pre-burn and 4 hours post-burn Commanding within 30 minutes of burn start
	26/34m radio metric	M-8 to 12 hours through M+ 12 hours
Cruise to L2 (F+ 4 to F+ 73)	70m with radio metric	1 support of 45 minutes
On-Orbit at L2 (F+ 74 to EOM)	70m with radio metric	1 support of 45 minutes
Delta V/Delta H Maneuvers at L2 (4 per year)	70m Near-continuous radio metric	1 support 4-6 hours M-8 to 12 hours through M+ 8 hours

L= Launch
F= Lunar Fly-by
M= Maneuver
MCC= Mid Course Correction (post fly-by)

Ground System Implementation Philosophy

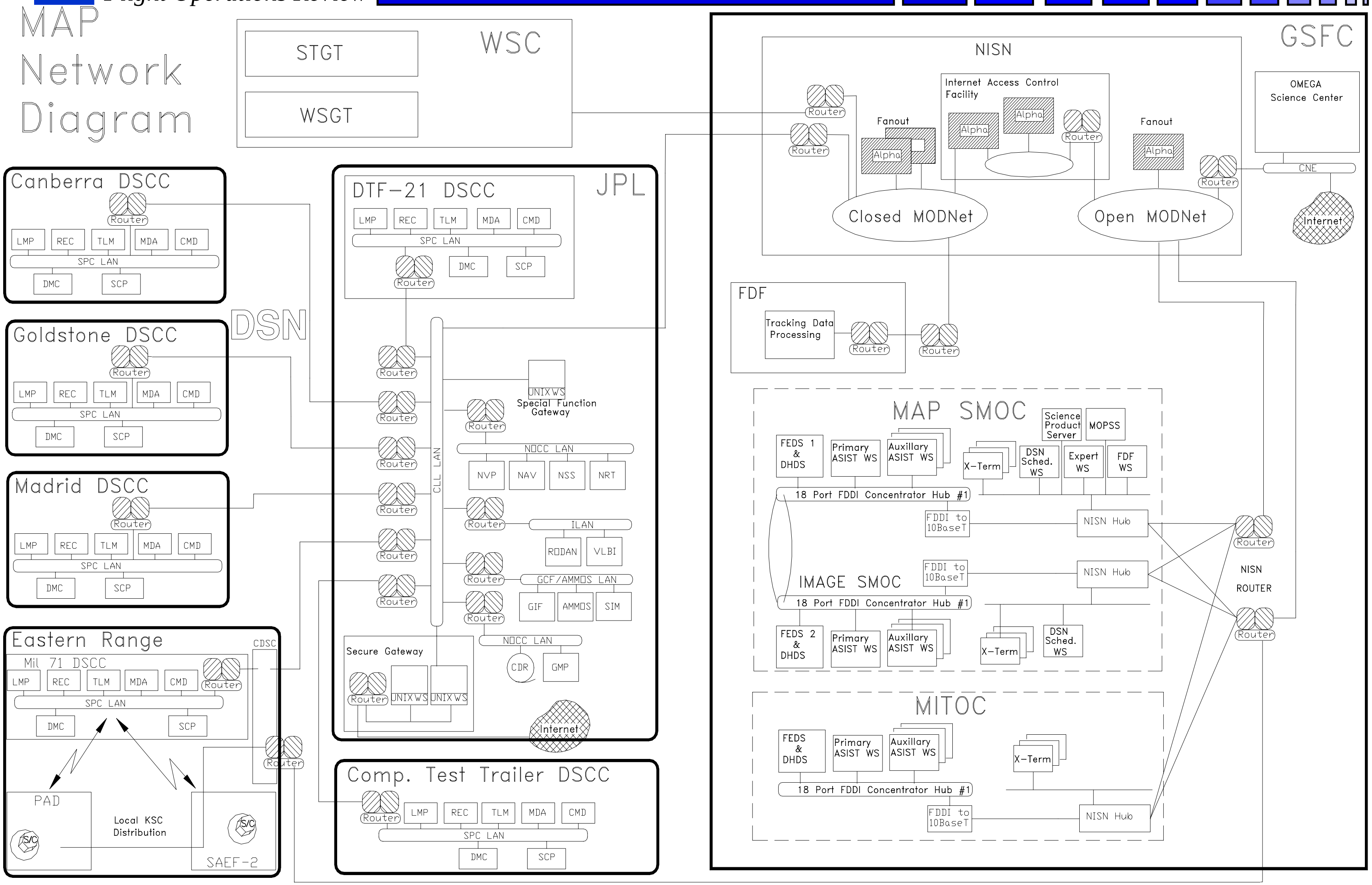
- **Single** Ground Data System to support **all** phases of the mission
  - Supported Component Development
  - Supporting Instrument Development
  - Supporting FSW Development
  - Supporting Spacecraft and Observatory I&T
  - Will Support On-orbit Operations
- Common Database
- Common Procedures
  - maximum runtime and maturity on all procs

Interface Commonality



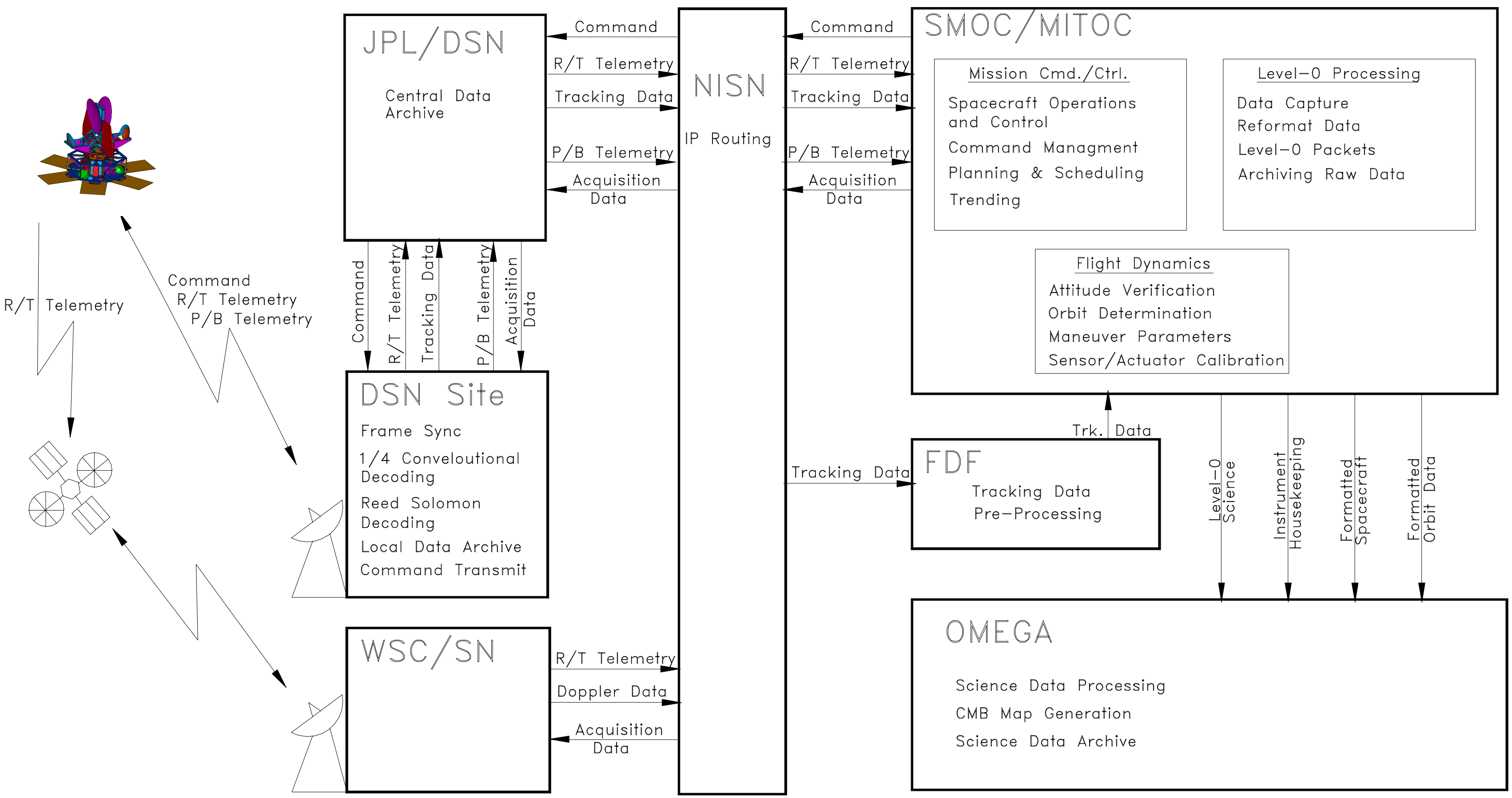
MAP Data Network

Flight Operations Review



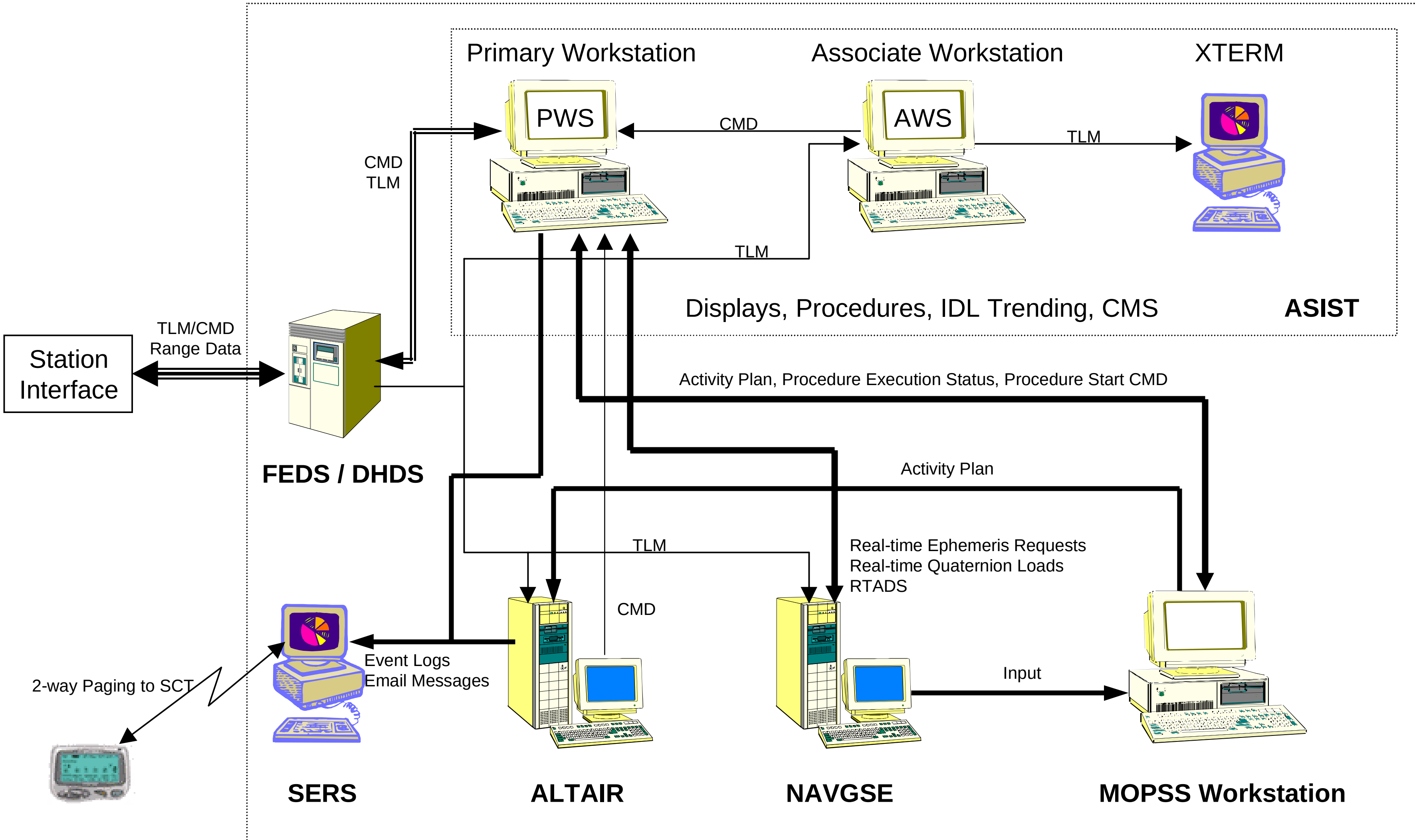
MAP Functional Data Flow

Flight Operations Review



Combined Ground System Diagram

Flight Operations Review



Combined Ground System (ASIST)

- **The Advanced System for Integration and Spacecraft Test (ASIST)** provides a distributed human / machine I/F
  - to the spacecraft and it's components
  - to the spacecraft GSE
  - hosted on IBM R/S 6000
- ASIST satisfies nominal real-time spacecraft support requirements for all phases of a mission
- Internal/external interfaces are CCSDS compliant
- Provides a consistent user interface from component development
- SAMMI is commercial GUI Package

Combined Ground System (ASIST)

- Database driven command, telemetry and GSE control
- Script driven test procedures using the Spacecraft Test and Operations Language (STOL)
  - Features; compiled STOL & parallel STOL
- <u>Heritage</u>: XTE and TRMM I&T and FSW Development, IMAGE Ops and EO-1 I&T and Ops

Combined Ground System (FEDS/DHDS)

- **Front End Data System (FEDS) / Digital History Data Storage (DHDS)** provides:
  - Front-end functions
  - Network access to Data Archive
    - command & telemetry
    - ranging data
    - S/C events
    - ground segment status/control
  - Level-zero processing
  - Frame accounting
  - Decompression
  - Archive - all data for the life of the mission

Combined Ground System (CMS)

- Ported to IBM AIX from HP/UX to support MAP.
- The **CMS**
  - accepts and validates command input
  - accepts and validates event input
  - Performs command constraint checking
  - creates, validates, generates, and transfers absolute and relative timetag loads
  - generates pass plans
- <u>Heritage</u>: originally developed to support SAMPEX and has been used to support FAST, TRACE, SWAS and EO-1.

Combined Ground System (other components)

- **NavGSE** for OD and planning product generation
  - Attitude data processing and analysis performed by Matlab
  - GTDS perform OD
  - Generate maneuver commands
- **Astrogator** for trajectory analysis and maneuver planning
- **Interactive Data Language (IDL)** based trending system. 100% of the data is available to the trending package
- **ALTAIR** is an expert system which performs health and safety monitoring of spacecraft and ground segment supported through state modeling
- **MOPSS** is the graphical mission planning engine
- **SERS** supports the paging and e-mail response

Other GSFC Support Elements

- **NISN** provides all operational voice and data circuit in support of the MAP mission. All mission operations voice and data circuits are configured to support the mission. Circuits to support the campaign at the Cape are defined in the LSSP, they are not configured.
- **MMFD** performs tracking data preprocessing and delivers the data to the NavGSE in the SMOC in near-realtime
- **NCC** will coordinate the interface with the SN. The NCC will schedule the TDRS supports. During the support the ND will monitor OPM data and generate any GCMR's

ASIST S/W Release Schedule

- Current Open “urgent” UPR’s
  - 7 ASIST
  - 4 FEDS
  - 3 CMS

- ASIST Release 8.1 - June 30, 2000
  - MAP Launch Release
  - No MAP Critical Capabilities or UPR’s

- Ground System S/W Freeze Date
  - L-3 Months (August 7, ‘00)

- ASIST Release 9.0 - January 31, 2001
  - MAP Post-Launch Cleanup Release

- ASIST Web Site
  (http://rs733.gsfc.nasa.gov/ASIST/ASIST-home.html)

Risk Assessment

- Minimal
  - Maximum Ground System Runtime with the Spacecraft
    - see “Box Runtime” chart for current status
  - SCT brought on very early
    - Component Development
  - Comprehensive Mission Simulation Schedule
  - Sufficient Software Development Staffing
  - Sufficient Budget
- Issues:
  - Long-term maintenance of the ground system
    - Currently no future missions have baselined the CGS for support

DSN Operations

Arthur Landon

DSN/CSOC CSR

art.landon@csoconline.com

Agenda

- Documentation Status
- Supporting Stations
- DSN Training Program
- DSN Configuration
- DSN - SMOC IP Comm Interface
- Compatibility Testing
- DSN Launch Readiness Review
- Lights Out Operations

Documentation Status

- Network Operations Plan (NOP)
  - Contains All DSN Configurations and Procedures for Support of the MAP S/C
    - NOP Includes Initial Acquisition Plan and DSN Test and Training Plan
  - Preliminary Scheduled for May 1, 2000
  - Final Scheduled for October 1, 2000
- Operations Agreement
  - Joint Operations Agreement between CSOC/JPL/MAP
    - Same as IMAGE Ops Agreement with Minor Mission Specific Changes

Supporting Stations

- Goldstone DSCC
  - **DSS-14 - 70 Meter**
  - **DSS-24 - 34 Meter BWG [2]**
  - **DSS-27 - 34 Meter HSB [2]**
  - **DSS-16 - 26 Meter [1]**
- Canberra DSCC
  - **DSS-43 - 70 Meter**
  - **DSS-34 - 34 Meter BWG [2]**
  - **DSS-46 - 26 Meter [1]**
- Madrid DSCC
  - **DSS-63 - 70 Meter**
  - **DSS-54 - 34 Meter BWG [2]**
  - **DSS-66 - 26 Meter [1]**

NOTES:

1. Used for Launch through Lunar Flyby and Contingency Support during Cruise to L2
2. Used for Launch through Lunar Flyby and Contingency Support during Cruise and L2 Operations

Test and Training Activities

- Mission Services Training Activities (MSTAs)
  - MSTA Program Runs Nominally from Launch -6 mo Through Launch
  - Encompasses Activities Formerly Know as Mission Readiness Training (MRT), Ground Data System (GDS) Testing, and Operational Readiness Testing (ORT)
  - MSTA Program Divided Into Two Phases
    - Phase I Primarily Internal DSN Mission Specific Training and Verification of Capability to Support Mission Specific Configurations
    - Phase II Geared to Project Test and Training Activities Even Though The Project May be Included in Some Phase I Activities

DSN Configuration

- Telemetry
  - On Site Frame Synchronization, Convolutional Decoding Either Rate 1/2 or 1/4, and Reed Solomon Decoding
  - Output Will Be Formatted Into SFDUs for Real-time Transmission to The MAP Project and Recording At the CDR for Post-pass Replay
- Monitor
  - Monitor Data Will Be Provided to the MAP SMOC by the NOCC-RT System For the 70m and 34m Stations
  - The 26m Stations Will Not Provide Monitor Data to The MAP Project

DSN Configuration (Cont'd)

- Command
  - MAP Will Use Throughput Commanding at 2Kb/s on a 16Khz Subcarrier
- Tracking
  - All Tracking Data Will Be Sent to MMFD for MAP
    - 70 and 34m Stations Provide Doppler and Range Data
    - 26m Stations Provide Doppler, Range, and Angle Data

Ground Communications

- MAP Will Utilize the ISIS IP Interface Between JPL and GSFC For All Data Except Tacking Data
  - Same Comm Interface Used By ACE, FUSE, and IMAGE
  - Fan-out at GSFC Responsible For Proper Routing of Data from JPL
- Tracking Data Sent Via NISN IP Interface Between JPL and GSFC
  - Standard Interface for Tracking Data to MMFD

Compatibility Testing

- Initial RF Compatibility Testing Performed November 18 - 21, 1998 at GSFC Using the DSN CTT
  - Test Results Published in DSN Document 872-014
- Tentative Schedule for Additional Testing In Place
  - RF Verification & End-to-End at GSFC 6/19/00 - 7/7/00
  - RF Verification & End-to-End at KSC 8/8/00 - 8/12/00
  - RF Verification & End-to-End at KSC 11/7/00 - 11/11/00

DSN Readiness Review

- A DSN Launch Readiness Review Will Be Scheduled Approximately 6 Weeks Prior to the Scheduled Launch Date

Lights Out Operations

- DSN Support of MAP Lights Out Operations Will Be the Same As For IMAGE Lights Out Operations
  - Currently Documented in DSN/IMAGE Ops Agreement
  - Will Be Tested, Verified, and Documentation Modified As Necessary After Image Launch and IOC
  - Will Be Documented in DSN/MAP Ops Agreement

Launch Site Operations

Nancy Stafford

AGENDA
Launch Site Operations

- **KSC Flows**
- **Launch Site Testing**
- **Launch Configuration**
- **KSC Reviews**

MAP LAUNCH SITE ACTIVITIES IN SAEF 2

Flight Operations Review

SET UP OBSERVATORY AND GSE IN SAEF 2 → OBSERVATORY VISUAL INSPECTION → INSTALL OMNIS & MEDIUM GAIN → POST-SHIP ALIGNMENT

FULL BATTERY RECONDITIONING → CPT #4 → MISSION SIMS → CLOSEOUT PROBLEM RECORDS →

ACS STIMULI, INSTRUMENT TARGETS INSTALLED

PROPULSION TESTING → INSTALL (2) BOTTOM THRUSTER COVERS → FINAL INTERNAL INSPECTION & CLEANING OF OBSERVATORY → INSTALL SOLAR PANELS /ELECTRICAL INTEGRATION → MLI INSTALLATION & C/O

LEAK & FLOW TESTS
INSTALL ENABLE PLUGS

DEPLOYMENT TEST
RF TEST

CSS PHASE TEST → MISSION SIMS → PAD FUNCTIONAL DRY RUN → CLOSEOUT PROBLEM RECORDS → DISCHARGE BATTERY & PREP TO LOAD PROPELLANT

INSTRUMENT TARGETS

LOAD PROPELLANT & PRESSURIZE → REMOVE SOLAR ARRAY GSE BARS → WET SPIN BALANCE TEST → BATTERY RECONDITIONIN G →

FLIGHT CONFIGURATION
INSTRUMENT COVERS OFF

INSTALL SOLAR ARRAY CABLE GSE BARS FOR SHIPMENT → PRE-CANNING CHECKOUT, INSPECTION, OF OBSERVATORY → WEIGH OBSERVATORY MATE TO PAF → INSTALL MAP ONTO DELTA THIRD STAGE

MAP/DELTA PAD FLOW

T-9 *Flight Operations Review* T-8

MOVE MAP IN TRANSFER CAN TO PAD

ERECT MAP ON TOWER/MATE TO VEHICLE

SHOWER CAP INSTALLED

VERIFY UMBILICAL INTERFACE TO OBSERVATORY

REMOTELY CONTROLLED FROM SAEF-2

MAP BATTERY FINAL CHARGE (GSE IN B/H) SKIN CONNECTOR & DUCT MATED

FAIRING & GN2 A.C. PREVIOUSLY VERIFIED PRIOR TO HOOKUP

T-7

MAP FUNCTIONAL TESTS (WITH INSTRUMENT TARGETS)

T-6

FLT. VERIFICATION & POWER-ON STRAY VOLTAGE

S/C IN LAUNCH MODE

T-5

POWER OFF STRAY VOLTAGE, ORDNANCE INSTALLATION & HOOKUP

LIMITED S/C ACCESS
TRICKLE CHARGE OFF/ON

MAP INSPECTION,RED & GREEN TAG PRE-FAIRING CLOSEOUTS FINAL CABLE TENSION

REMOVE GSE S/A BARS,
INSTRUMENT COVERS/TARGETS
DISCONNECT INSTRUMENT PURGE

T-4

FAIRING INSTALLATION, MAP SHORT FUNCTIONAL

REHOOK BATTERY A.C.
DUCT THRU FAIRING DOOR

T-3 **FRR**

FAIRING FINALING, PROP LOAD PREPS

T-2

2ND STAGE PROPELLANT LOADING

MISSION REHEARSAL
LIMITED S/C ACCESS

T-1 **LRR**

BEACON, RANGE SAFETY & CLASS A ORDNANCE

LIMITED S/C ACCESS

T-0

MAP FINAL INSPECTION & RED TAG CLOSEOUTS

REMOVE GPS A.C.
START GN2 PURGE

LAUNCH CONFIGURATION, DELTA COUNTDOWN

Launch Site Testing

- **Full Observatory testing after transport to KSC in SAEF-2. (CPT, Mission Sims, Pad Functional)**
  - Verify no damage has occurred following shipment to KSC.
  - Final verification of software.
  - Verify all commands and hardware connections.
  - Continued data trend analysis.
  - Verify all ground interface configurations.

- **Pad Functional (Prior to fairing encapsulation)**

  - Observatory is in flight configuration
  - Battery AC
  - Umbilical Console GSE
  - Battery Support Provided by SAS through Umbilical
  - Safing Plugs installed for propulsion, solar array deploy
  - RF GSE (TURFTS)- RF Radiates Using a Pickup Antenna
  - ACS Stimuli - Will NOT be available on pad
  - Instrument Targets in place
  - Instrument purged

Verify all commands and hardware functionality/connections after observatory is mated to the launch vehicle

- **Pad Functional (After fairing encapsulation)**

  - Observatory is in flight configuration
  - Battery AC
  - Umbilical Console GSE
  - Battery Support Provided by SAS through Umbilical
  - No RF radiation
  - No Instrument Testing
  - Safety Critical Commands Inhibited

At the conclusion of this test the isolation valve will be opened in preparation for launch. This activity will be verified by telemetry and current measurement.

Launch Site Operations

- **Verify Launch Operations Configuration with the LV (Mission Rehearsal)**
  - Participate in a launch day simulation on the pad with the launch vehicle to demonstrate and verify the launch-operations configuration and message transmission timelines.

- **Final Launch Day verification (Launch Day Power up)**
  - Perform an aliveness test to all launch and early orbit critical components prior to placing the observatory into launch configuration.

MAP Launch Configuration

- **Power Subsystem**
  - PSE RSN On
  - Timer set at L-15 minutes to turn wheels on at separation.
  - Observatory on Internal Power at L-5 minutes.
  - Engine Valve Driver (EVD) Thruster Power On.
  - Reaction Wheels are OFF
  - Solar Arrays Stowed.
  - Solar Array Module On.
  - Battery Support Provided by SAS Power through Umbilical.
  - Battery State of Charge >95%.
- **C&DH**
  - HSKP RSN in Launch Mode.
    (Waiting to detect separation and initiate SA Deploy H/W seq.)
  - Filter Table in Launch Mode/MV Archive in Launch Mode.
  - Command Uplink Rate - 2KBps, Telemetry Downlink Rate - 2KBps.

Launch Site Operations

ï

- **Flight Software**
  - MAC Mongoose V in Launch Mode
  - Launch FDC.
    - Selected TSMs and RTSs enabled, loaded and ready.
- **RF**
  - Transponder RSN #1 and #2 ON
  - Receivers On
  - Transmitters OFF
  - Switch Configuration
    - SW#1 - OMNI, SW#2 - Med Gain
- **Thermal**
  - Survival Heaters On

- ï• **ACE**
  - MAC ACE RSN in Launch Mode
    - ï Holds wheel drive until separation detection.
  - Coarse Sun Sensors (CSS) On.
  - Digital Sun Sensor (DSS) On.
  - Inertial Reference Units (IRU) On
  - Pressure Transducer On.
  - LMAC ACE RSN OFF.
    - ï All powered services are off.
  - Valve Driver Power is OFF.
  - Catbed Heaters OFF.
  - Autonomous Star Tracker (AST) #1 and #2 OFF.
- **Propulsion Subsystem**
  - Thruster Valves Closed.
  - Isolation Valve Opened.
  - Prop Line Heaters On.
- **Instrument**
  - OFF.

Launch Site Reviews

- Ground Operations Review at KSC
- MAP Readiness Review (after CPT at SAEF-2)
- Launch Site Readiness Review (LSRR)
- MAP Readiness Review (after Functional on the Pad)
- Flight Readiness Review (FRR)
- Mission Rehearsal
- Launch Readiness Review (LRR)
- Launch Day Readiness

Launch Site Operations

- **Ground Operations Review at KSC**
  - This review is held at the KSC approximately one month prior to shipment to review and verify all ground data links.

- **MAP Readiness Review after CPT at SAEF-2**
  - This review is an internal technical review of the entire observatory. It is conducted at KSC in SAEF-2 after the completion of all of the Comprehensive Performance Testing and prior to moving the observatory to SLC 17.

- **Launch Site Readiness Review (LSRR)**
  - The purpose of this review is to verify the readiness of the launch vehicle and spacecraft for the transfer of the spacecraft to the pad. This is primarily a Delta II review. Spacecraft processing activities at SAEF-2 are also reviewed.

Launch Site Operations

- ï• **MAP Readiness Review after Functional Testing on Pad**
  - After all functional testing on the pad is completed and the fairing is encapsulated a final observatory internal technical review is conducted. All PRs, PFRs, WOs are closed and red tag/green tag items are identified.

- **Flight Readiness Review (FRR) (T-3 days)**
  - This review is conducted to verify that after checkout the launch vehicle and spacecraft are ready for countdown and launch. Launch readiness of the range to support launch is also determined.
  - After the review is completed, the okay for second stage loading of propellants is given.

Launch Site Operations

- **Mission Rehearsal (T-2 days)**
  - The goal of the rehearsal is to assure readiness, accomplish certification of the Mission Control Team personnel and verify procedures prior to the mission. This test will demonstrate the MDC launch-operations configuration and that message transmission timelines meet mission support requirements. The MAP Launch Team will participate in this rehearsal.

- **Launch Readiness Review (LRR) (T-1 day)**
  - This review requires that the range, customer, spacecraft contractor, and launch vehicle contractor provide a ready to launch statement. Upon completion of this meeting an okay to enter terminal countdown is given.

Launch Site Operations

ï• Launch Day Readiness

- Launch day activities are highly structured and disciplined. Range, launch vehicle, and spacecraft activities are integrated into the Launch Preparation Document (F1) Countdown Manual. Tasks in the Countdown Manual and pre-planned ready- and go- statements are used by the Mission Control Team members to demonstrate readiness and launch commit for nominal conditions. This activity confirms:

  1. Readiness to enter countdown.
  2. Concurrence to proceed with major events/tasks.
  3. Readiness to proceed at completion of planned holds.
  4. Readiness to proceed with terminal countdown.
  5. Readiness to load LOX.
  6. Permission to launch.

Normal Operations

Steven Coyle

Glen Miller

Peter Gonzales

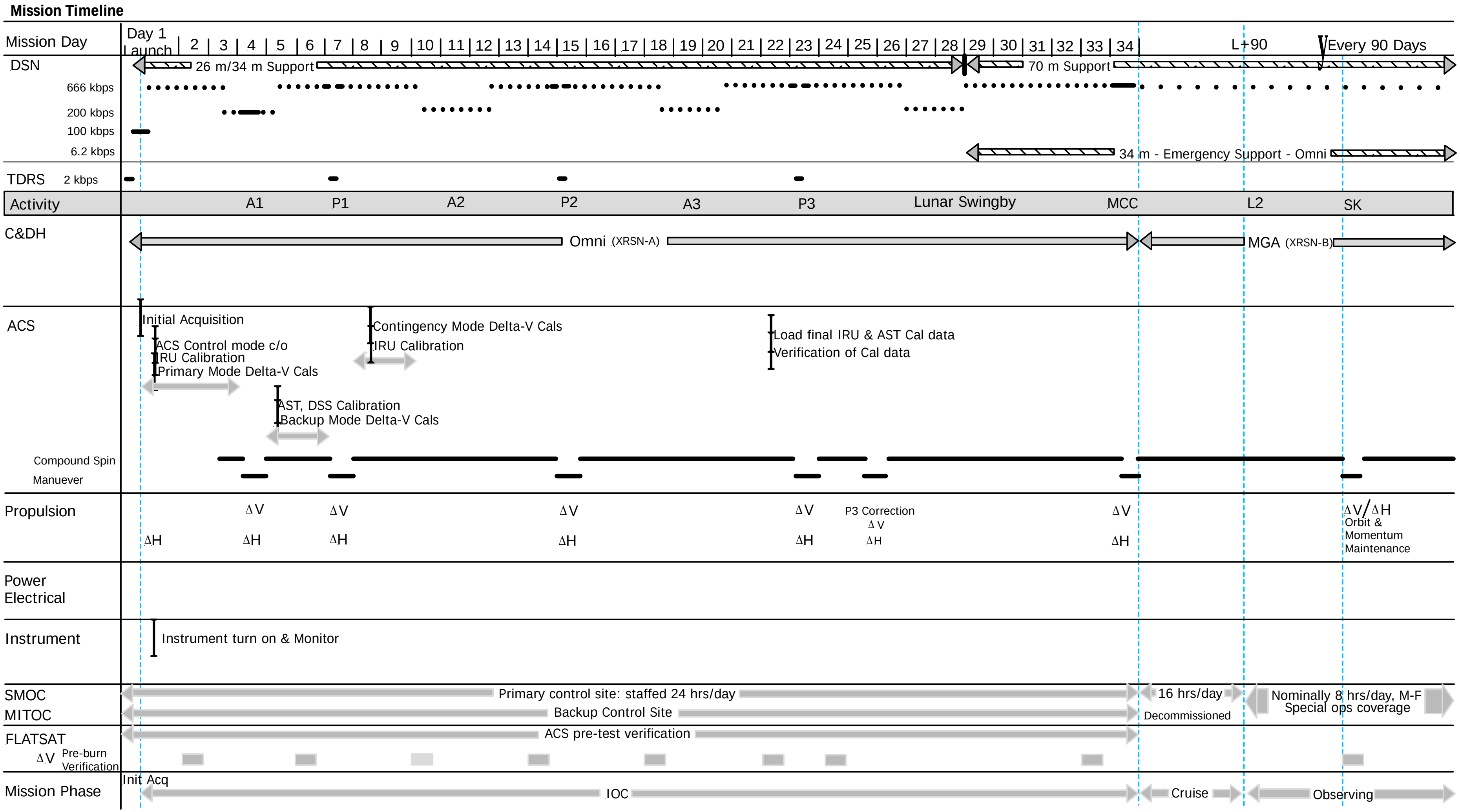
Gary Hinshaw

Detailed Mission Timelines

Steven Coyle

Nominal Operations
Mission Summary Timeline

Flight Operations Review



Nominal Operations
Mission Summary Timeline

- Mission Phases
  - Launch & Initial Acquisition
  - IOC - Days 1 to 34
  - Cruise - Days 35 to 90
  - Observing - Days 91 to EOL

- IOC:
  - ACS control mode verification & sensor calibrations
  - Execution of maneuvers to effect the trajectory to L2
  - Instrument turn on and verification, begin characterization
  - IOC ops supported with the DSN 26 or 34 m antenna
  - Perigee maneuvers supported by TDRS

Nominal Operations
Mission Summary Timeline

- Cruise:

  - Primarily Instrument Characterization as thermal stability approached

  - Automation of operations is verified and transitioned to during this period

- Observing:

  - Routine Science Operations Executed

  - Stationkeeping Maneuvers/Momentum Unloads are the only interruption to science data collection. (At most 4 times per year)

  - Normal daily pass operations handled solely by automated systems.

Nominal Operations Launch Sequence

Pre-Launch/Launch Sequence		
Step	**Launch**	**Activity Description**
1	L - 13:00:00*	Establish Voice Links
2	L - 12:00:00*	MAP Turn On and check spacecraft
3	L - 06:30:00	MST Removal and Securing
4	L - 06:15:00	Configure Initial Launch Mode
5	L - 06:00:00	Solid Motor Arming
6	L - 03:30:00	Built in Hold: T-150 Hold (60 minutes)
7	L - 03:30:00	All MAP Prime Shift Stations on console
8	L - 02:45:00	MD Poll 'GO' for Terminal Countdown
9	L - 02:40:00	NASA Launch Manager Poll of MD
10	L - 02:30:00	End of Hold: Terminal Countdown Initiated
11	L - 02:20:00	Configure for 2 Kbps mode. Verify Launch Configuration.
12	L - 02:15:00	First Stage Fueling
13	L - 01:25:00	Begin LOX Loading
14	L - 00:45:00	Verify Final Launch Configuration
15	L - 00:30:00	KSC and GSFC Spacecraft Engineer Launch 'GO/NO GO' Poll
16	L - 00:25:00	MOM and SCTs, Ground System Engineers (GSFC and KSC) Launch 'GO/NO GO' Poll
17	L - 00:15:00	MD 'GO/NO GO' Poll for Launch
18		Start Timers to turn on Catbed Heaters, Transmitter, RWs post-launch
19		Start Mongoose V Recorder
20	L - 00:14:00	Begin T-4 Hold (10 minutes)
21		MAP Management Team makes decision to GO Internal at L-00:05:00
22	L - 00:13:00	NASA Launch Manager Poll of Mission Director for GO for Launch
23	L - 00:10:00	MD announces MAP GO for Launch
24	L - 00:06:00	MD Notifies NASA Launch Manager Decision to GO Internal at L-00:05:00
25	L - 00:05:00	MAP transitions to Internal Power
26	L - 00:04:00	End of T-4 Hold: Final Countdown Started.

Nominal Operations Launch Sequence

Flight Operations Review

Pre-Launch/Launch Sequence

Step	Launch	Activity Description
27	L - 00:00:00	LAUNCH
28	L + 00:00:35	Mach 1
29	L + 00:00:51	Maximum Dynamic Pressure
30	L + 00:01:03	Solid Motor Burn Out
31	L + 00:01:06	Solid Motor Separation
32	L + 00:04:21	Main Engine Cutoff
33	L + 00:04:27	Vernier Engine Cutoff
34	L + 00:04:31	Stage 1/2 Separation
35	L + 00:04:37	Stage 2 Ignition
36	L + 00:04:54	10 ft Fairing Separation
37	L + 00:11:32	Stage 2 Cutoff
38	L + 00:59:37	Omni to TDRSS at 2 Kbps
39	L + 01:02:42	Start Stage 3 Ignition Time Delay Relay, fire spin
40	L + 01:02:45	Stage 2/3 Separation
41	L + 01:03:22	Stage 3 ignition
42	L + 01:04:00	3rd Stage (Mid) Burn
43	L + 01:04:38	Stage 3 Burn Out
44	L + 01:09:32	Deploy Yo-yo weights
45	L + 01:09:37	Separation
46		Solar Array Deployment
47		ACS sun acquistion mode active
48		Omni to DSN 26 m at 100 kbps
49		Contingency Momentum Unload
50	Sep + 00:35:00	Power Positive and on sunline

Nominal Operations
IOC: Days 1 to 8 Timeline

IOC: Days 1 to 8 Timeline

Mission Day	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8
DSN 666 kbps 200 kbps 100 kbps TRACKING DATA	26 m/34 m		26 m/34 m 200 kbps	26 m/34 m	26 m/34 m 666 kbps	26 m/34 m	26 m/34 m 2 kbps	26 m/34 m
TDRS 2 kbps							2 kbps	
Activity				Apogee			Perigee	
C&DH	XRSN-A UPL/DL Omni			Apogee Delta-V ATS execution			P1 Delta-V ATS execution	
DS PB/Dumps								
ACS	AST pwr on & c/o KF c/o (Sun Acq) Thruster Pulse Test Delta-H c/o ACE-A Safehold c/o Verify CSS+IRU & CSS Only KF c/o (Inertial) ACE-B Safehold c/o Verify CSS+IRU & CSS Only Inertial Slew test, CQT c/o, & rough IRU Cal check. Small single axis slews, first slew by ground cmd, remaining from CQT	IRU Cal Slews Large slews at reduced rates Delta-V X-axis, 4 thruster test Observing Mode c/o (KF not enabled for test)	Load IRU Cal Data Initial cal data from Day 2 IRU Cal Slews Verify cal data loaded Delta-V +Z-axis test Delta-V -Z-axis test Observing Mode with KF Collect DSS, AST cal data Passive data collection during modified Observing mode	Potential Apogee Delta-V OR Delta-V X-axis, 4 thruster, CQT test Delta-V +Z-axis, CQT test Makeup slot (Days 4–5)	Delta-V -Z-axis, CQT test Makeup slot (Early in day) (Days 5–6)	Load IRU, DSS, AST Cal Data	P1 Delta-V	Backup Delta-V mode tests: Thrusters 5,6 Thrusters 7,8 **NOTE: Ops could advance to Day 5 if no Apogee Delta-V required.**
Propulsion	Thruster Pulse test Delta-H c/o	Delta-V test	Delta-V tests	Apogee Delta-V OR Delta-V tests	Delta-V test		P1 Delta-V	Delta-V X-axis, 2 thruster tests
Power Electrical	BSOC at 100 %							
Instrument	Instrument Turn on and monitor		Observing mode c/o					
FLATSAT	Ver Day 2 Delta-V test	Ver IRU cal data load file Ver Day 3 Delta-V tests	Ver Day 4 Delta-V tests (or Apogee Delta-V)	Ver Day 5 Delta-V test	Ver Day 6 IRU/DSS/AST cal data load files	Ver P1 info/params	Ver Day 8 Delta-V tests	Ver Day 9 ACS tests
Comments	IOC operations begin following initial sun acq and stable on sunline S/C left in Sun Acq while unattended	S/C left in Sun Acq while unattended	S/C left in Observing while unattended if test OK, else S/C put in Sun Acq					

Nominal Operations
IOC: Days 1 to 8 Timeline

- Compressed Execution of IOC Operations

  - All critical ACS verification and calibration operations must be executed within the first 6 days (first Perigee maneuver is on Day 7).

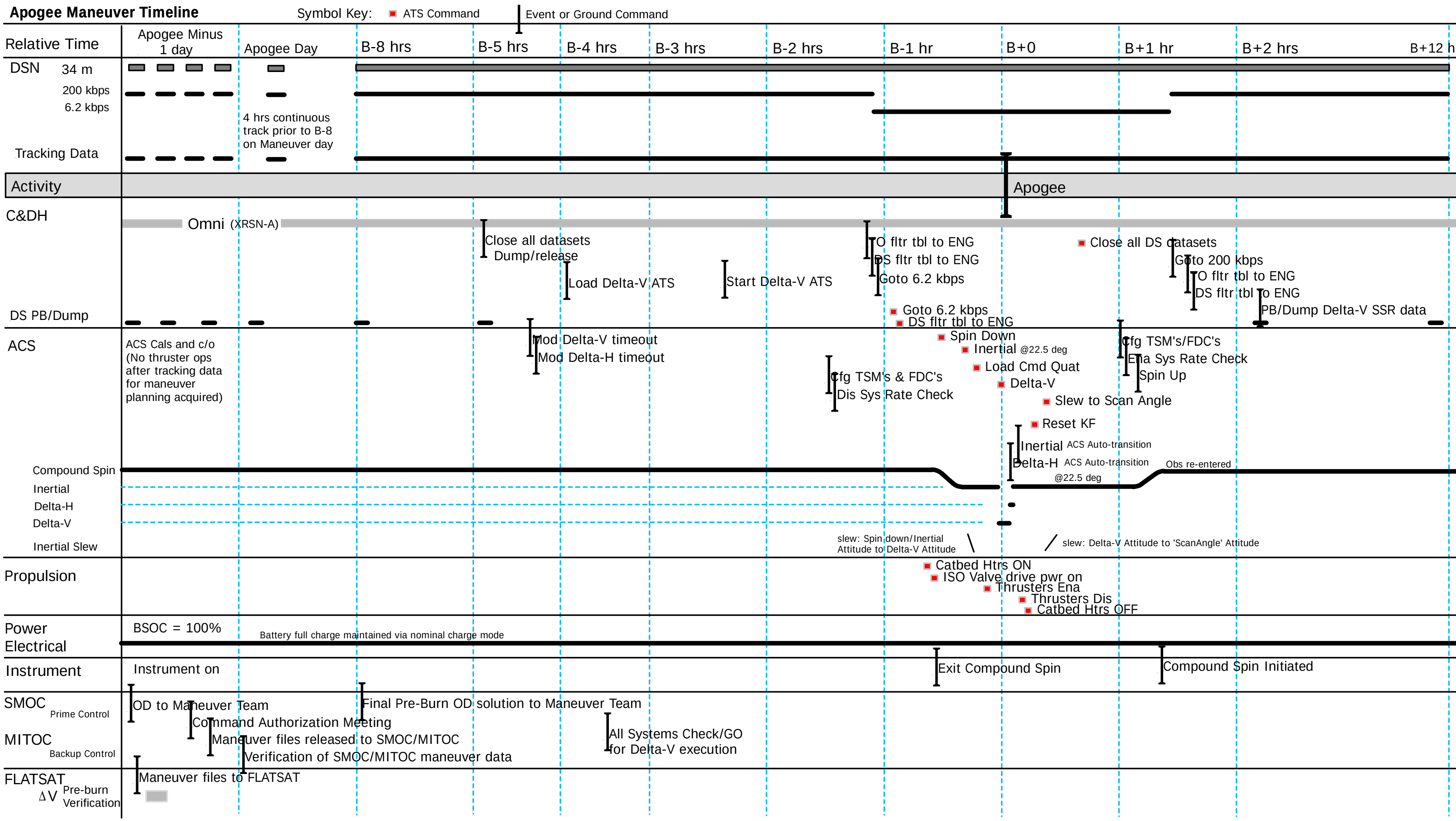
  - IOC operations begin shortly after Initial Acquistion with basic ACS and Safehold tests.

  - Verification & Calibration operations are scheduled so that control modes and sensors are verified/calibrated prior to their usage in a critical operation.

  - Verification & Calibration of Delta-V modes covers both non-CQT and CQT maneuvers.

Nominal Operations
Apogee Maneuver Timeline

Flight Operations Review



Nominal Operations
Apogee Maneuver Timeline

- Potential Maneuver at first Apogee

  - A first Apogee pass maneuver may/may not be required.

  - A place holder for this operation is included in the IOC timeline.

  - Apogee Delta-V is a Non-CQT maneuver.

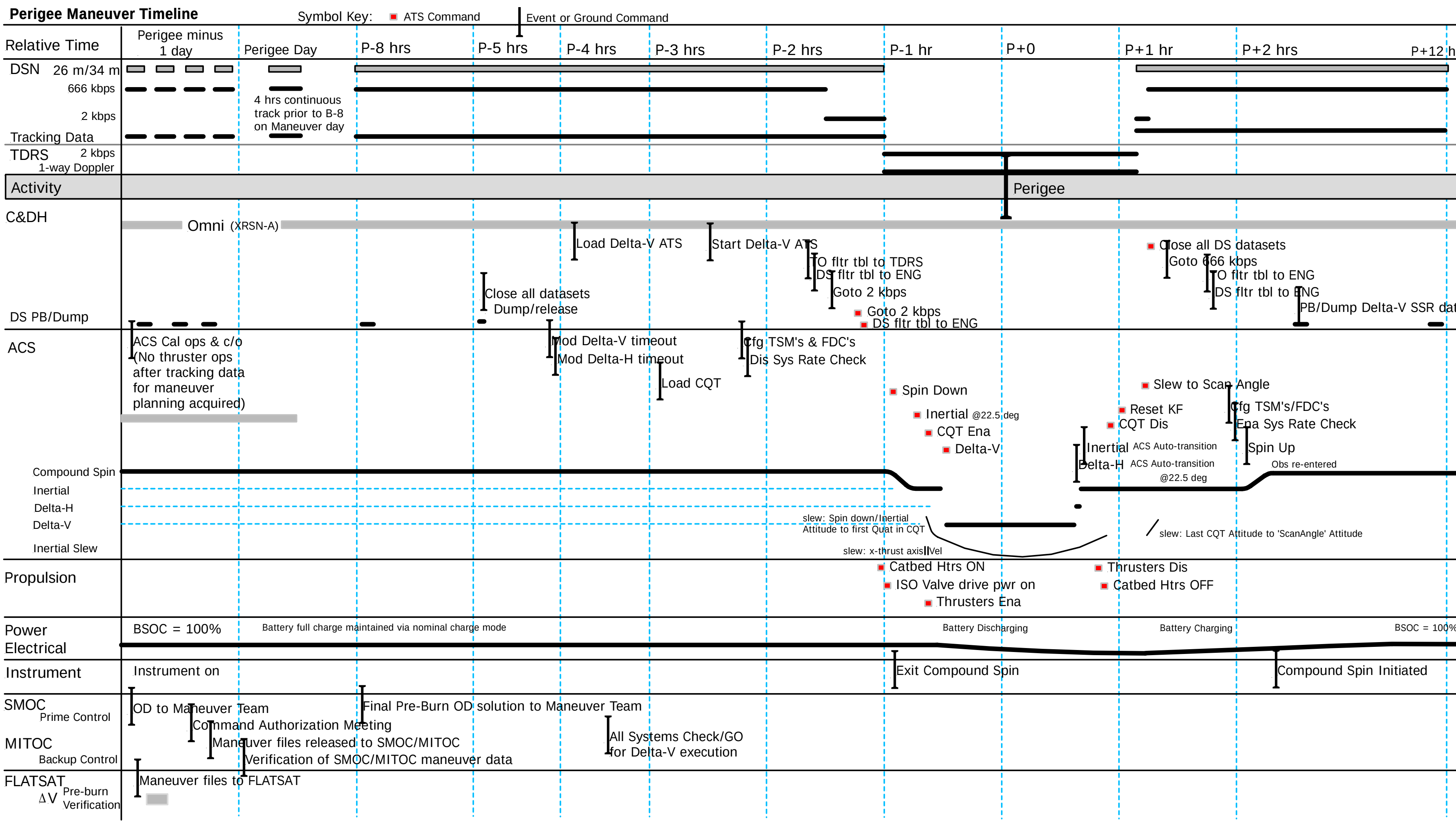
  - DSN provides continuous Telemetry and Command capabilities throughout the maneuver operations.

  - A combination of Ground commanding and ATS commanding is used to execute an Apogee Maneuver.

  - ATS is used to provide precise command execution timing.

Nominal Operations
Perigee Maneuver Timeline

Flight Operations Review



Nominal Operations
Perigee Maneuver Timeline

- Perigee Maneuvers

  - Perigee Maneuvers use the CQT

  - DSN provides Telemetry and Command during approach and retreat from perigee.

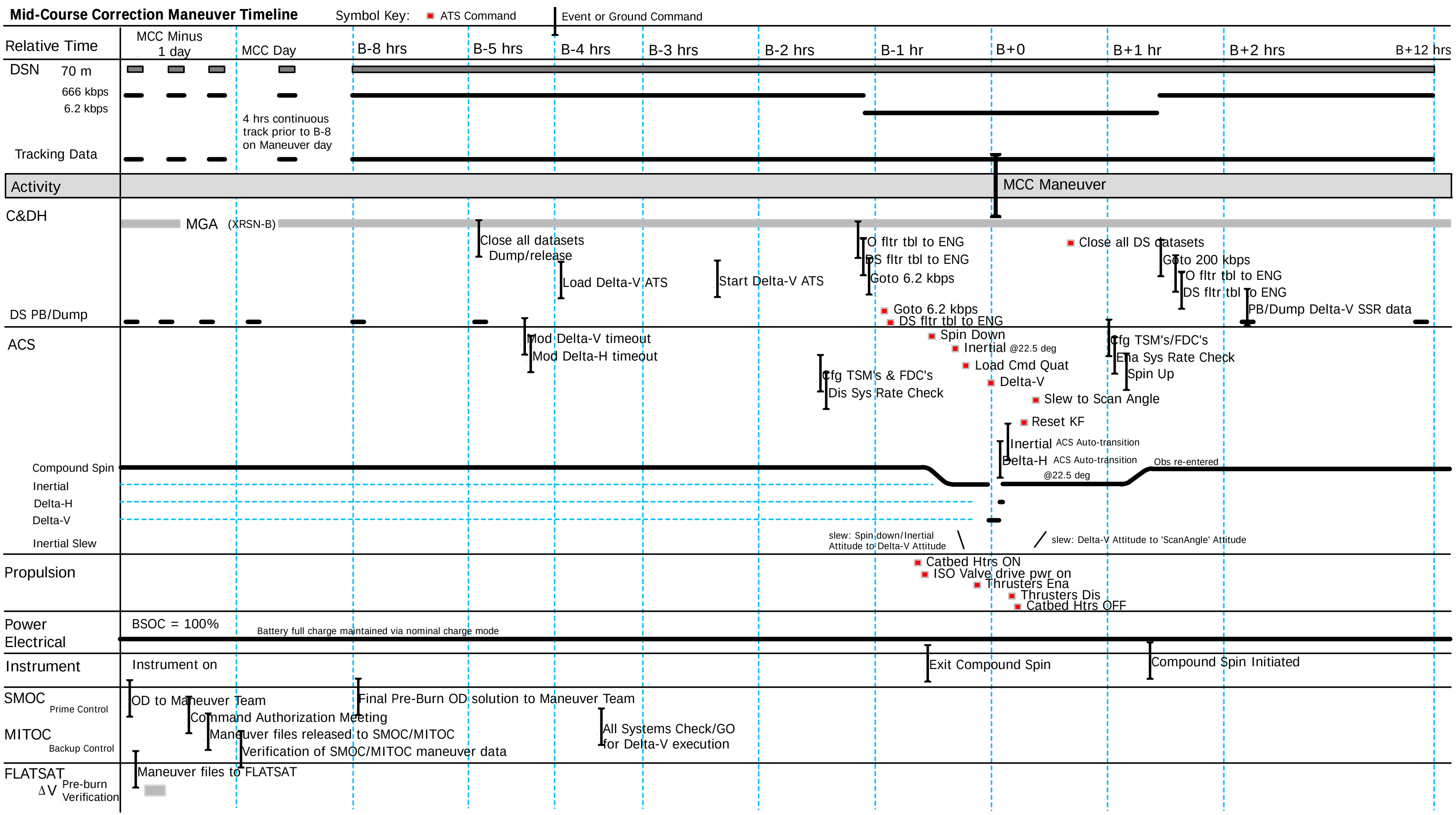
  - TDRS provides Telemetry and Command during actual perigee passage.

  - A combination of Ground commanding and ATS commanding is used to execute a Perigee Maneuver.

  - All required commands during TDRS support phase originate from the ATS. The ATS provides precise command execution timing; also, this eliminates the dependency on commands through TDRS during a critical operation.

Nominal Operations
Mid-Course Correction Maneuver

Flight Operations Review



Nominal Operations
Mid-Course Correction Timeline

- Mid-Course Correction Maneuver

  - MCC Delta-V is a Non-CQT maneuver.

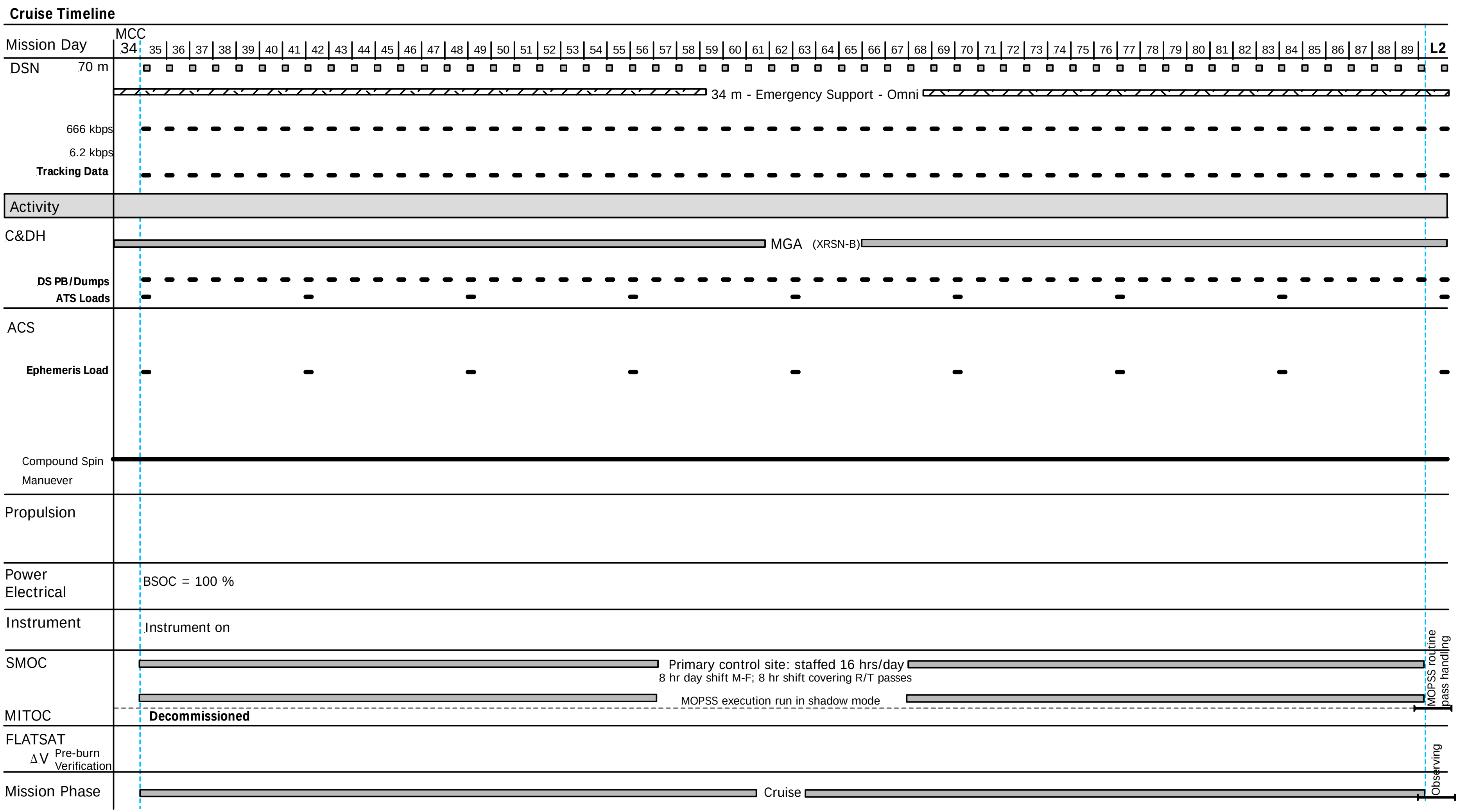
  - DSN provides continuous Telemetry and Command capabilities throughout the maneuver operations.

  - A combination of Ground commanding and ATS commanding is used to execute the Mid-Course Correction Maneuver.

  - ATS is used to provide precise command execution timing.

Nominal Operations Cruise Timeline

Flight Operations Review



Nominal Operations
Cruise Timeline

- Cruise Timeline

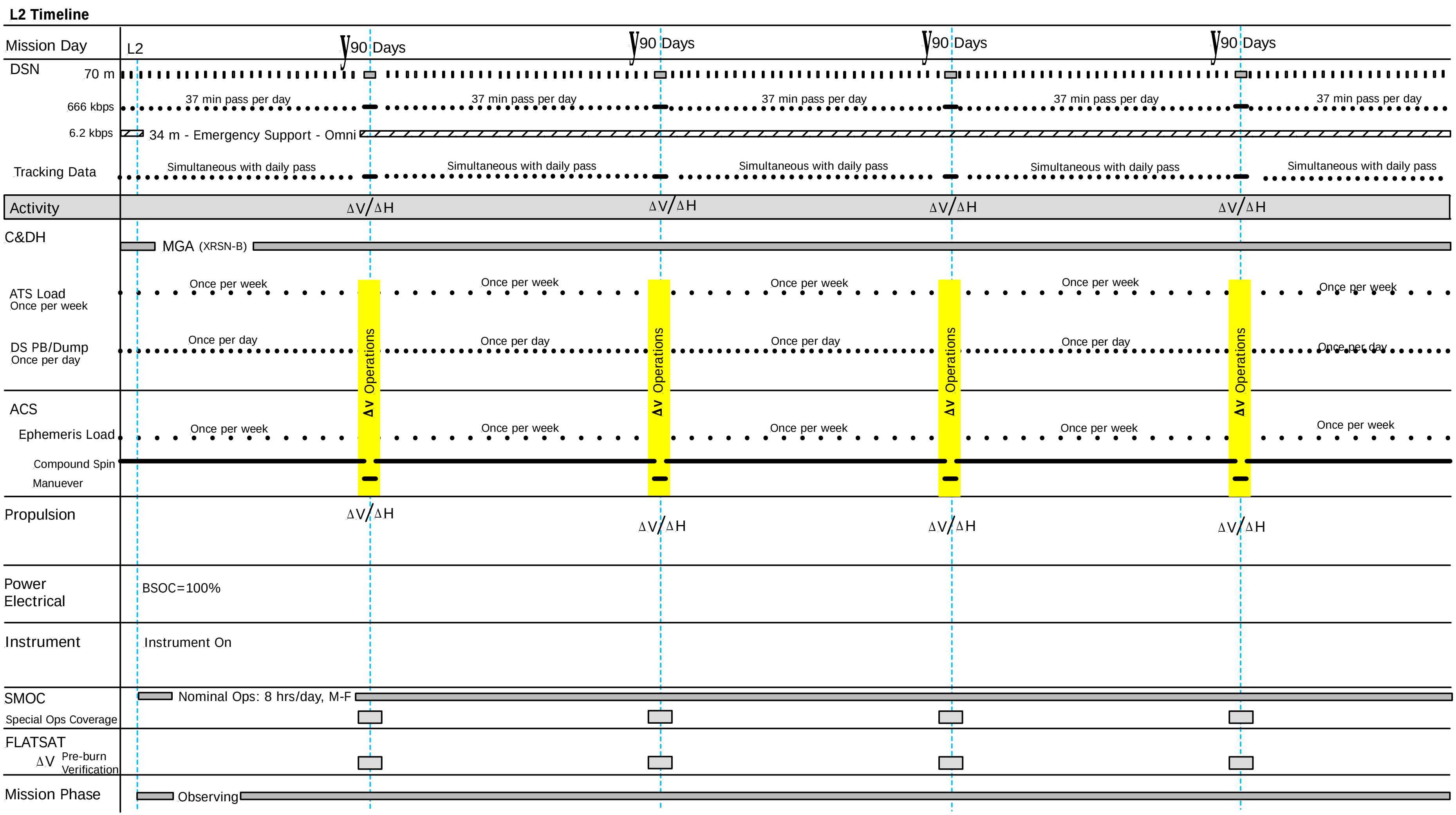
  - Compound spin maintained throughout this phase.

  - Instrument characterization and trending.

  - Off-line automation work: MOPSS Test & Verification in shadow mode.

Nominal Operations L2 Timeline

Flight Operations Review



Nominal Operations L2 Timeline

- L2 Timeline

  - Observing mode interrupted only by Stationkeeping/Momentum dumping operations (No more than 4 times per year).

  - 90 Day Cycle

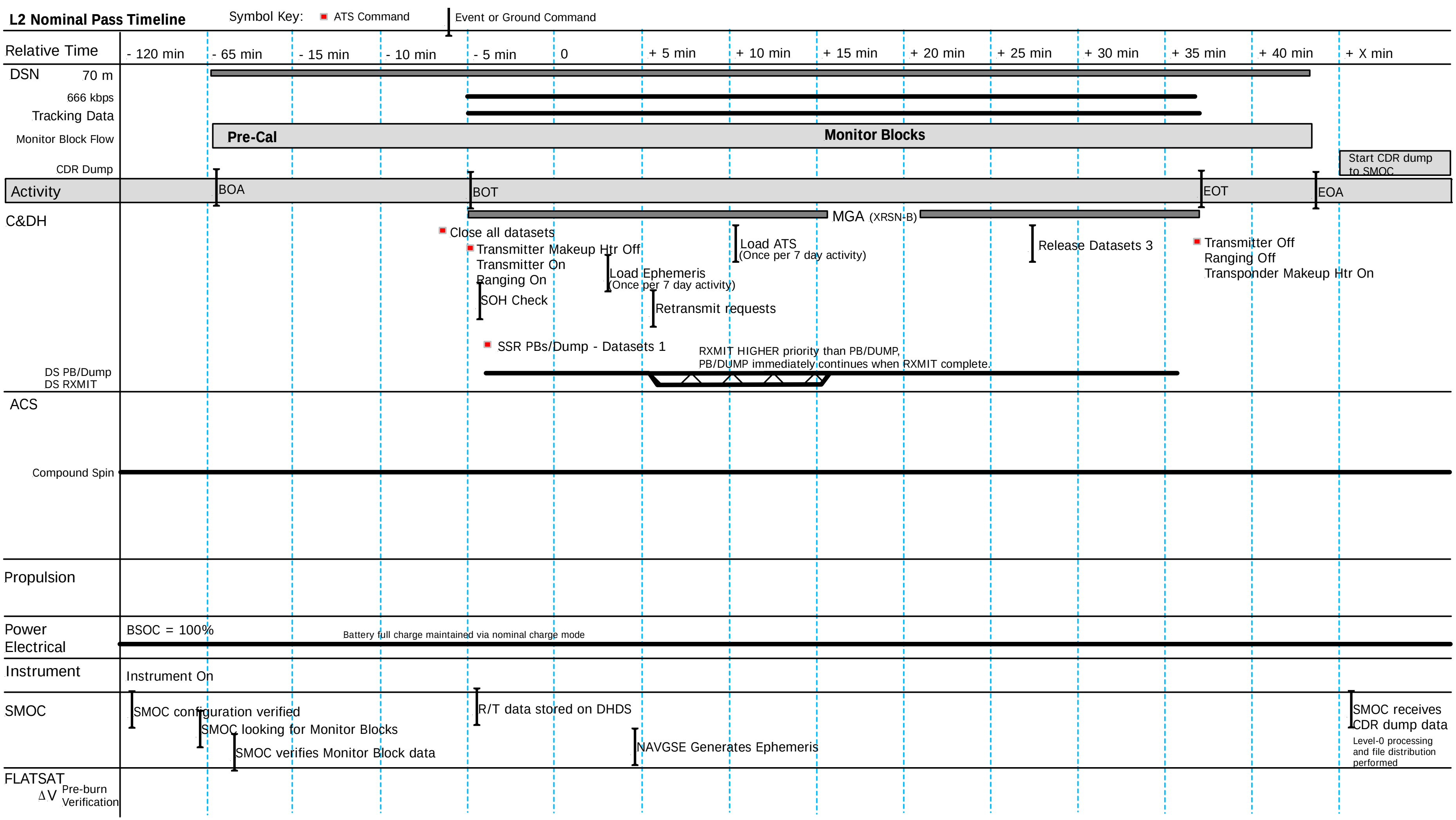
  - Daily operations consist of a single 37 minute pass

  - Tracking data collected during each pass

  - Nominal pass operations handled by automated systems

Nominal Operations
L2 Nominal Pass Timeline

Flight Operations Review



Nominal Operations
L2 Nominal Pass Timeline

- L2 Nominal Pass Timeline

  - Daily pass operations are simple and repetitive from day to day

  - Transmitter On/Off handled by ATS

  - SSR dataset closure/dumps handled by ATS

  - Retransmits and Release of SSR datasets handled by Ground

  - ATS loads performed once per week

  - 2 ATS buffers used with staggered, overlapping period

  - Ephemeris load performed once per week, processing verified during pass

Nominal Operations
L2 Nominal Pass Timeline

- L2 Nominal Pass Timeline

  - Realtime data processed during pass

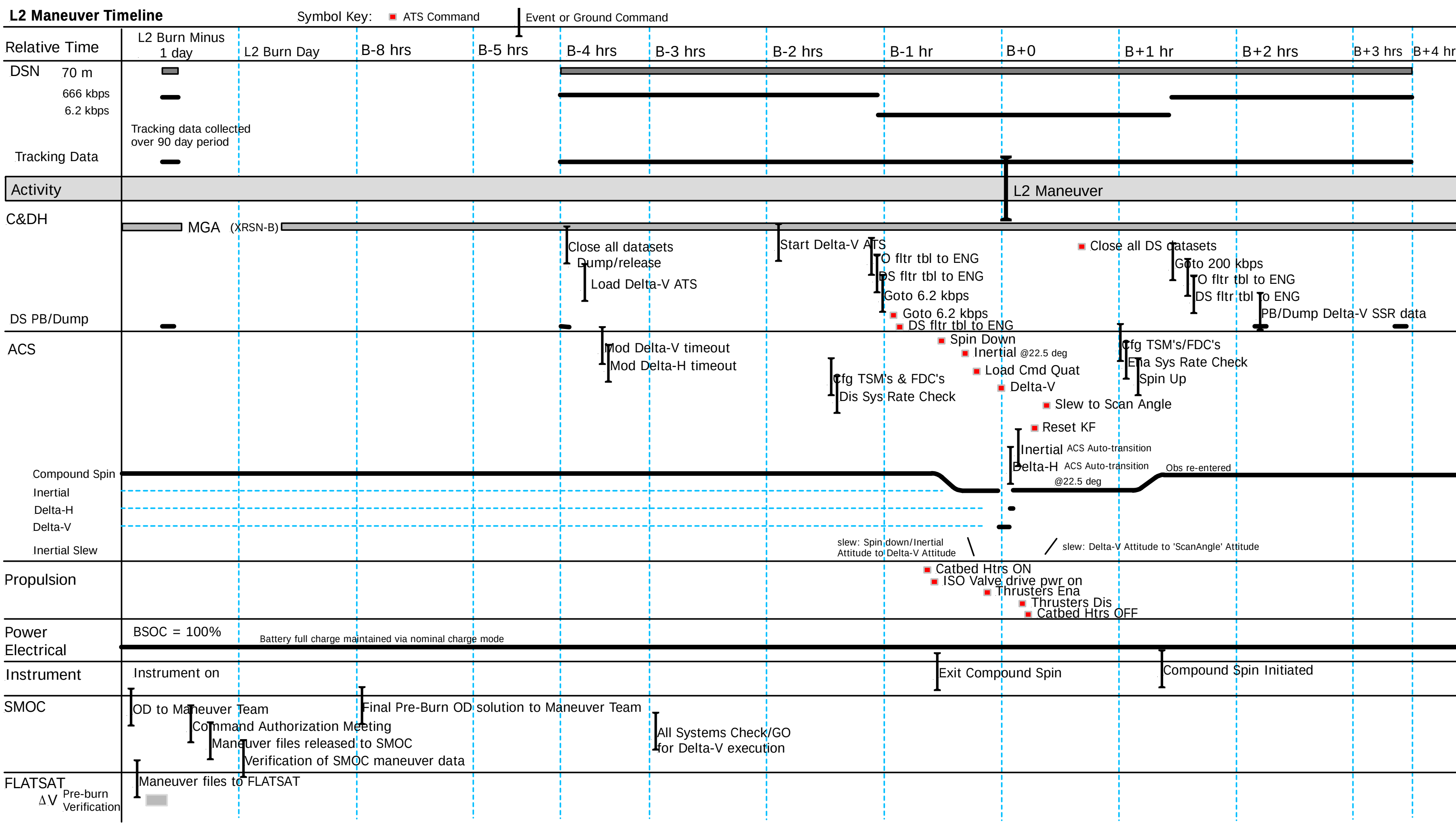
  - SSR dumped data transferred from DSN CDR to SMOC following pass

  - Automated Level-0 processing and transmission of data files to Omega

  - Automated processing of SSR dump statistics and setup for retransmits on next days pass

Nominal Operations
L2 Maneuver Timeline

Flight Operations Review



Nominal Operations
L2 Maneuver Timeline

- L2 Maneuver Timeline

  - Orbit solution based on tracking data collected over 90 days.

  - L2 Maneuver operations compressed, only 4 hours pre-burn & 4 hours post-burn tracking data.

  - DSN provides extended support for L2 Maneuvers.

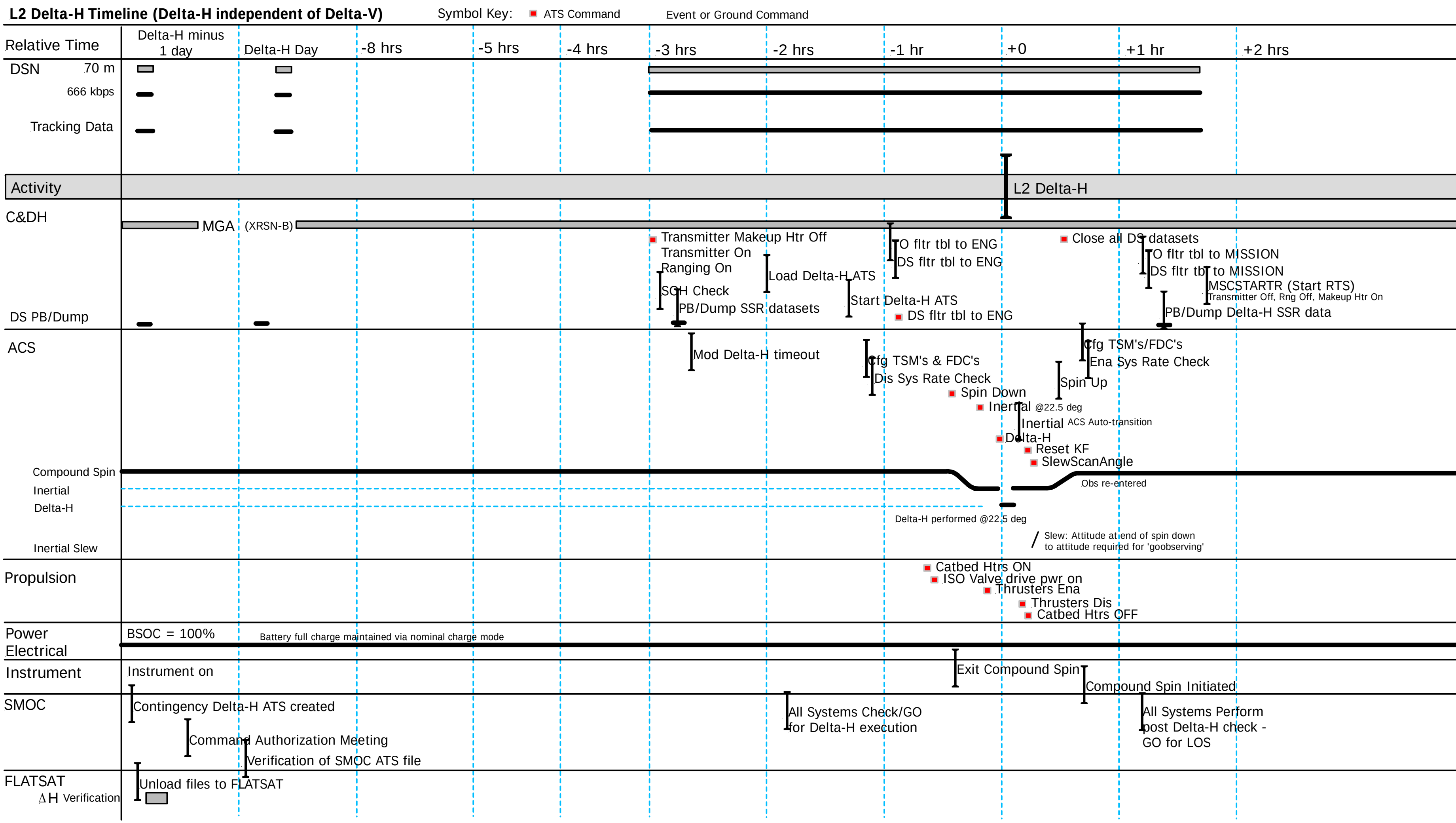
  - L2 Maneuvers are Non-CQT maneuvers.

  - No autonomy associated with L2 Maneuvers.

  - A combination of Ground commanding and ATS commanding is used to execute the L2 Maneuvers.

Nominal Operations
L2 Momentum Unload Timeline

Flight Operations Review



Nominal Operations
L2 Momentum Unload Timeline

- L2 Momentum Unload

  - Momentum Unloads are part of the normal Maneuver execution sequence: ACS autonomously enters Delta-H mode upon exiting Delta-V mode.

  - Momentum Unloads Independent of Maneuvers: Only required if by chance or planning no orbit adjustment is required for a given quarter however a momentum dump is required.

  - DSN provides Telemetry and Command coverage throughout the Momentum Unload operations.

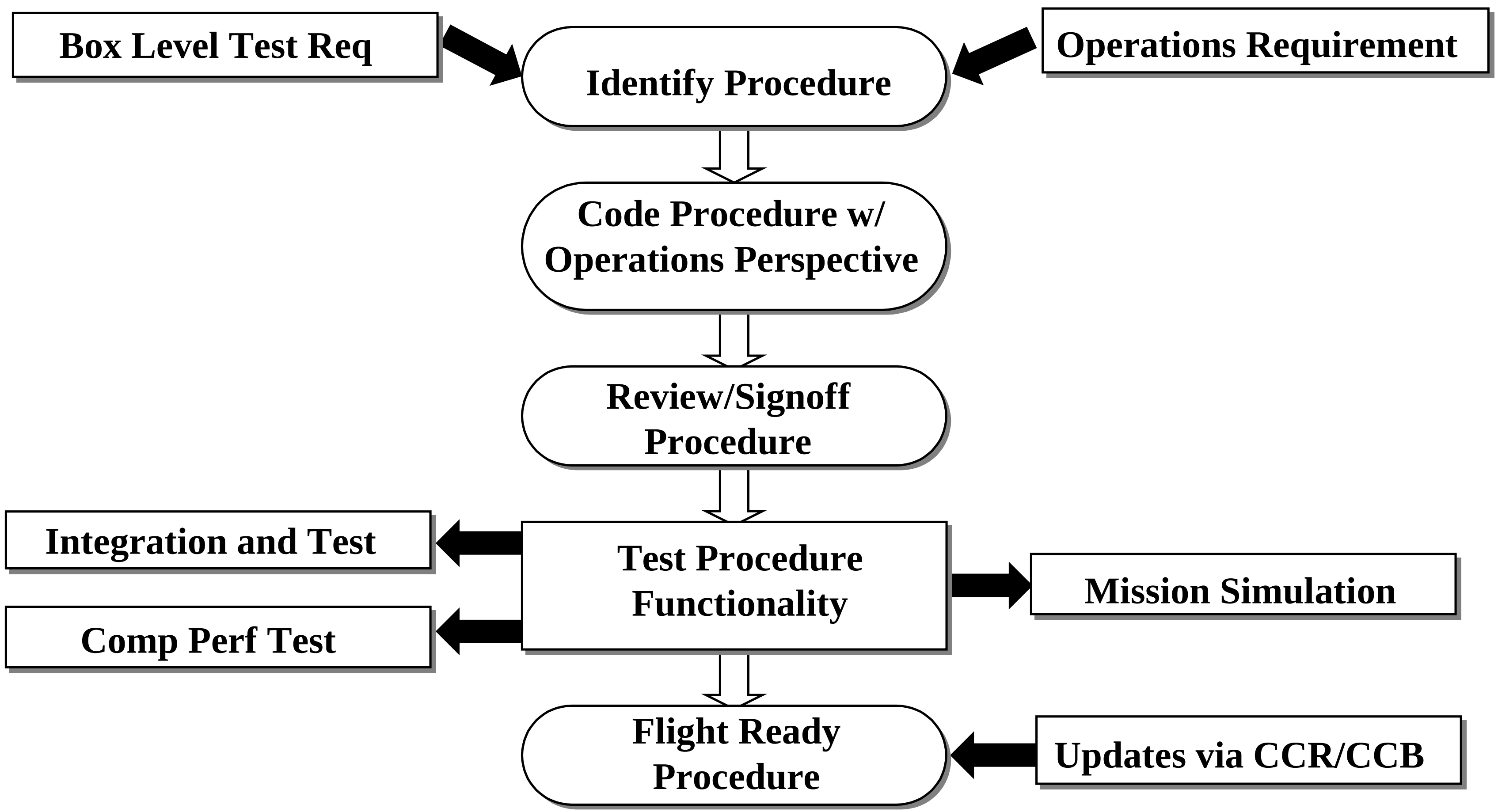
  - Delta-H operations are more compressed than the Delta-V operations, primarily due to the elimination of tracking data collection requirements.

  - A combination of Ground commanding and ATS commanding is used to execute the Delta-H.

Procedure Status
Trending Plan
Level Zero Processing
Mission Planning and Scheduling

Glen Miller

Procedure Evolution



Procedure Management

- All STOL procedures are maintained under SCT administered Procedure Configuration Management (CM) Control Plan
  - Project Database Guidelines (MAP-MODA-OPS-39) set naming conventions, style, content, and file location
  - Procedures are reviewed and signed off by:
    - Subsystem Lead
    - SCT Lead or Spacecraft Controller who authored procedure
    - Systems engineer
    - QA representative
  - All procedures are identified with:
    - Revision designator
    - Date of revision
    - Name of person who made revision
    - Detailed description of changes introduced since last revision

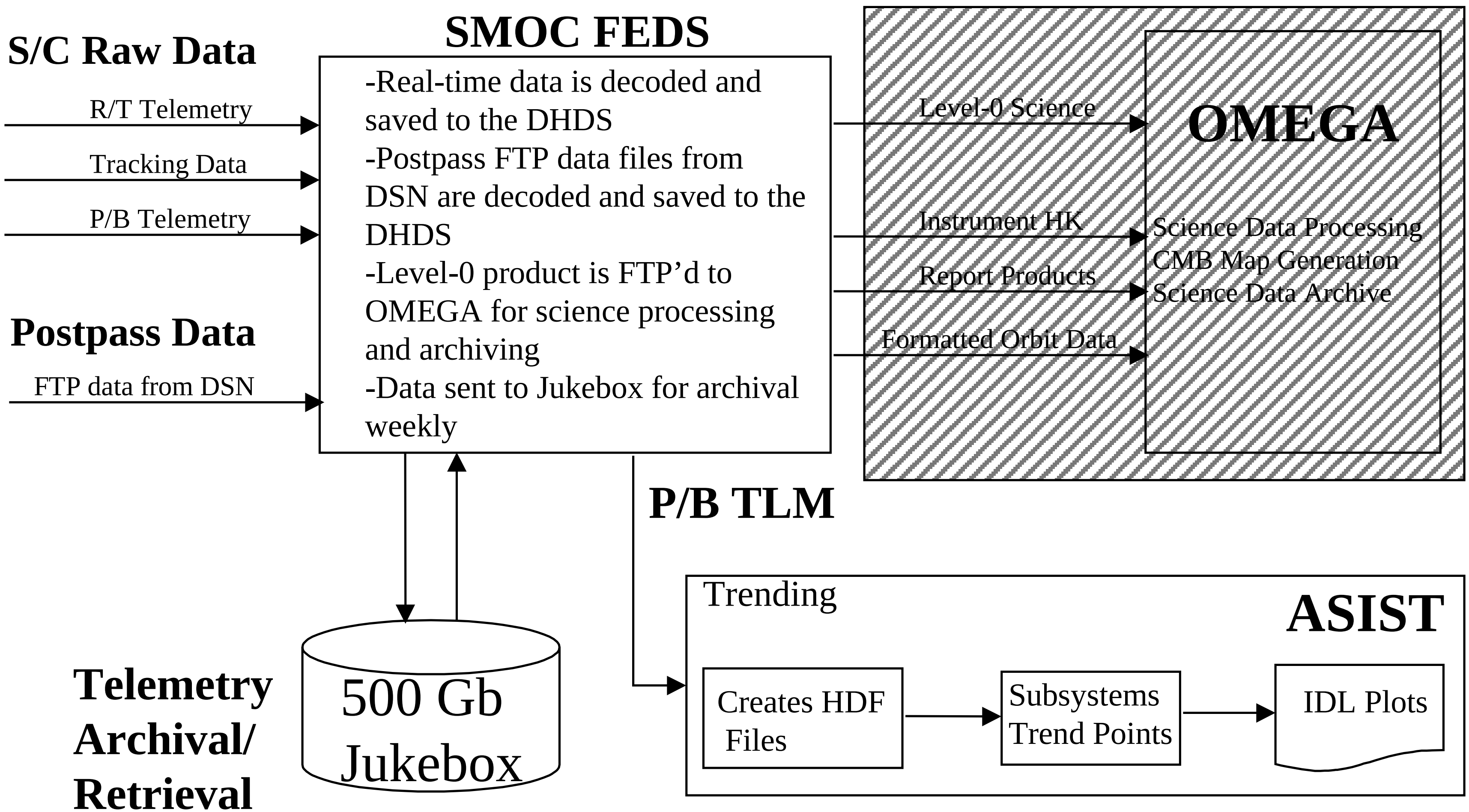
Procedure Management

- Signed-off procedures reside in configuration controlled directory
- Current revision procedure listing resides in binder at console
    - Alphabetical listing of all procedures
    - Original signature page for each procedure
- All procedures are executed with the S/C and/or FLATSAT
    - Mission simulations in place to exercise functionality
- Procedure modification/creation during Flight requires Configuration Change Request (CCR) and Configuration Control Board (CCB) approval

Procedure Status

	Identified	Written / Under Development	Tested on S/C and/or FlatSat	% Completed/Tested
Normal Mission Operations	**10**	**10**	**10**	**100.00%**
Launch/In-Orbit Checkout Operations	**30**	**10**	**10**	**33.33%**
Contingency Operations	**50**	**17**	**6**	**12.00%**
Special Operations	**34**	**33**	**33**	**97.06%**
Totals	**124**	**70**	**59**	**47.58%**

Post Pass Data Analysis (Trending)



Post Pass Data Analysis

- Trending Plan
  - APPROACH: To provide long term trending for specific HK parameters throughout the life of S/C
    - Perform Trending/Analysis on a daily basis using IDL via ASIST
    - Plots and/or statistical information will be provided to the subsystem engineers / instrument team for the parameters they require
    - Max/Mean/Min statistics will be stored on jukebox and/or hard drive for the life of the mission
    - Unique reports may be generated for any desired timespan
    - Generate quarterly reports for each subsystem and instrument

Post Pass Data Analysis

- Trending Software
  - IDL
    - COTS product
    - GUI directly interfaces with ASIST
    - Can be customized to support specific report requests
    - Can be run in background
  - Unique reports may be generated for any desired time span
    - Trend plots of one or more telemetry points vs time
    - XY plots of a telemetry point vs one or more telemetry points
    - Statistical plots vs time
  - Accessible via any network terminal

Post Pass Data Analysis

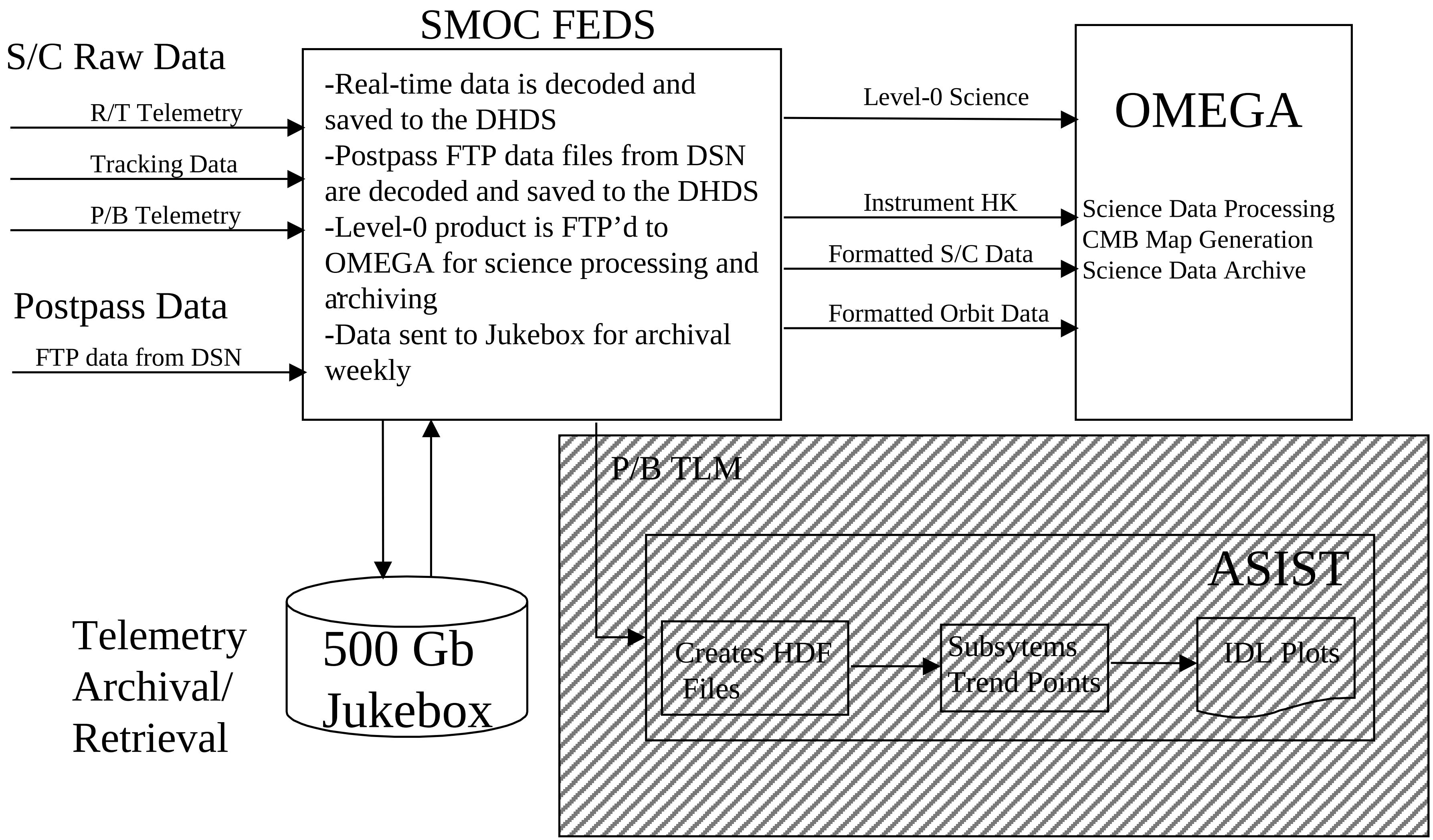
- Trending Process
  - Trend parameters are identified by subsystem engineers and experimenters
    - Mnemonic(s)
    - Trend period is user defined
  - Type of trending products are identified
    - Plots of one or more telemetry points vs time
    - XY plots of a telemetry point vs one or more telemetry points
    - Statistical plots vs time
  - ASIST creates Hierarchical Data Format (HDF) files by playing back telemetry data for specified time period from the FEDS
  - IDL, using identified parameters, will create trending products
  - Trending product is delivered to subsystem engineers or experiment team

Post Pass Data Analysis

- # of Subsystem Identified Trend Parameters (396 total)
  - 45 ACE
  - 98 ACS
  - 48 C&DH
  - 23 Propulsion
  - 12 RF/Comm
  - 12 FSW
  - 158 Instrument

- Meetings with Subsystem Engineers / Instrument Team will further refine parameter list and product requirements

Post Pass Data Analysis (Level-0 Processing)

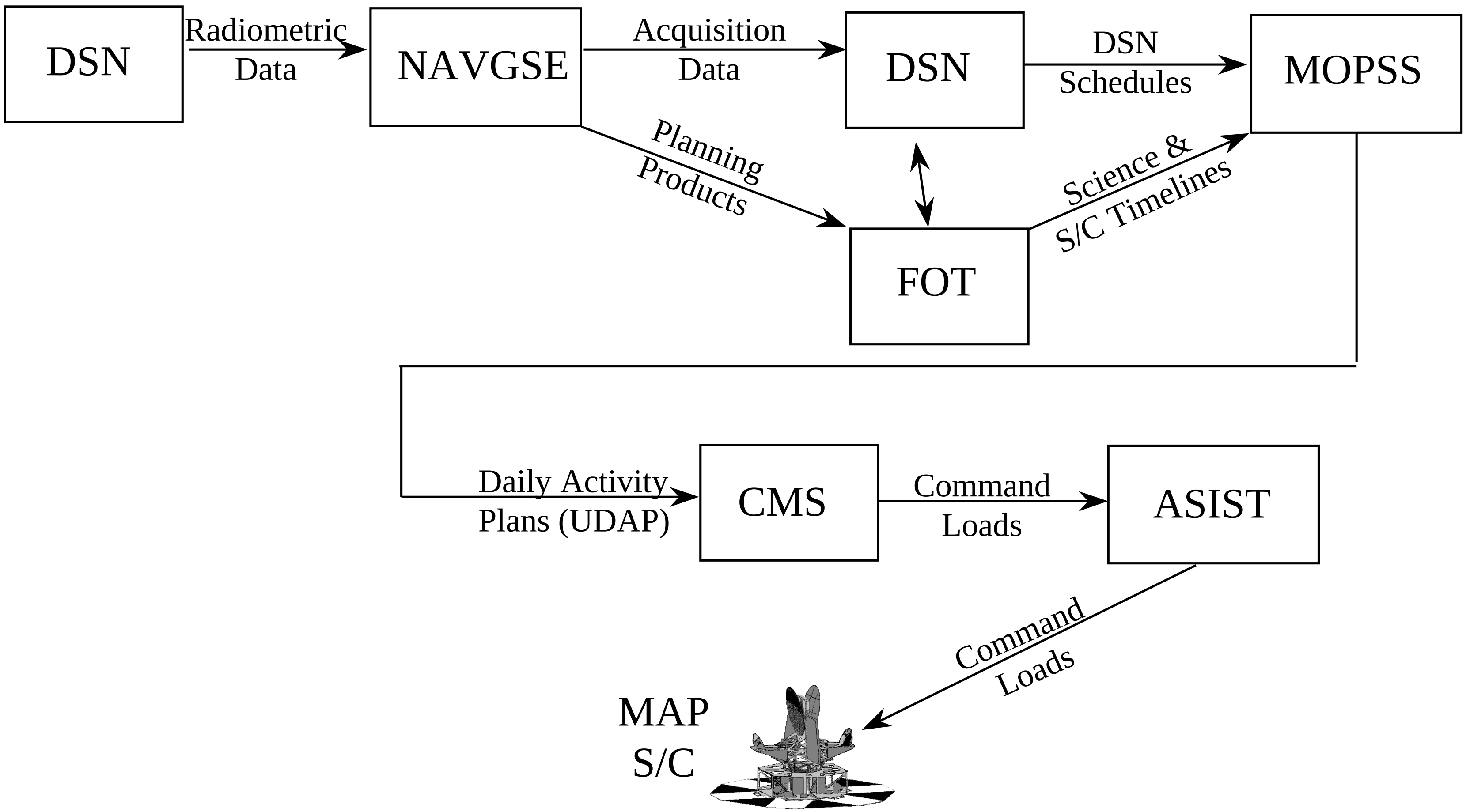


Post Pass Data Analysis

- Level-0 Processing
  - The SMOC FEDS receives raw S/C data transmitted from DSN
    - Real-time data is decoded and saved to the DHDS
    - Postpass FTP data files from DSN are decoded and saved to the DHDS
      - science data packets are decompressed
  - DHDS data is then Level-0 processed
    - If there are sequence breaks in the data, the SCT will generate a Data Retransmit Command for the next day's pass
    - The retransmitted data is FTP'd by DSN, decoded by the FEDS, and saved to the DHDS
    - DHDS data is then played back through the FEDS and is Level-0 processed
  - The resulting Level-0 product is FTP'd to OMEGA for science processing and archiving

Mission Planning Data Flow

Flight Operations Review



Mission Planning Data Flow Cont.

DSN -

- Sends Radiometric Data acquired from the MAP S/C to the NAVGSE
- Uses Acquisition Data and FOT input to generate contact schedules

NAVGSE -

- Ingests the preprocessed Tracking data from MMFD. Generates acquisition data, that the DSN uses to generate its contact schedules
- Generates Planning Products, that the FOT uses to generate Science & S/C timelines

FOT -

- Uses Planning Products to generate Science & S/C timelines, and provides schedule requests to the DSN

Mission Planning Data Flow Cont.

MOPSS -

- Uses DSN Contact Schedule and Science & S/C timelines to create User Daily Activity Plans (UDAP's) for CMS

CMS -

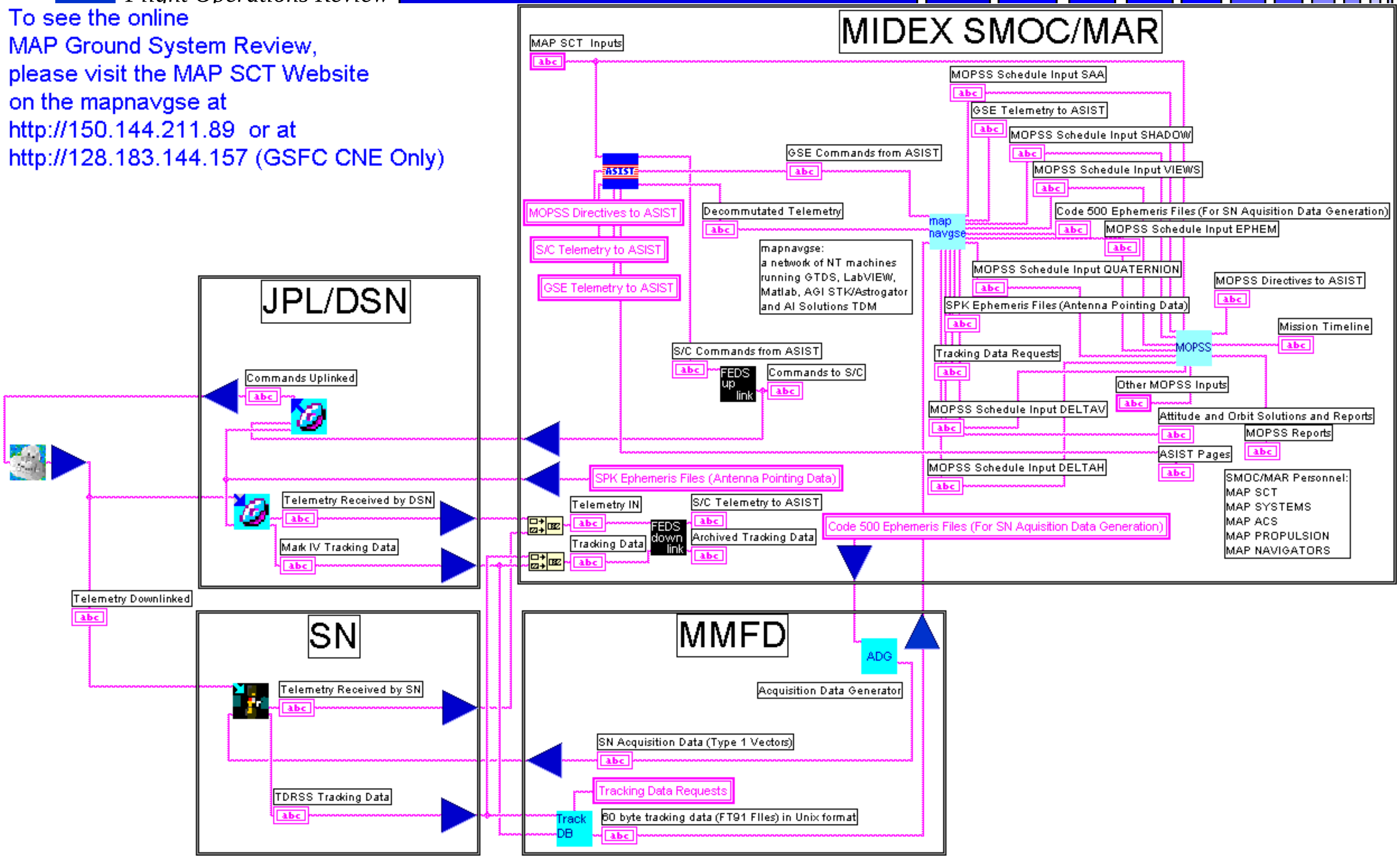
- Generates Command Loads from MOPSS provided UDAP's

ASIST -

- Uplinks Command Loads to the MAP S/C during DSN contacts

MAP Ground System Overview
(from a Navigator's POV)

To see the online
MAP Ground System Review,
please visit the MAP SCT Website
on the mapnavgse at
http://150.144.211.89 or at
http://128.183.144.157 (GSFC CNE Only)



ICD's and Implementation

- ICD's for OD data and products
  - Each interface will be documented with respect to:
    - file format
    - transport protocol
- OD pipeline in automated
  - Generates OD data and planning products
  - no human intervention required
- OD and Maneuver tools
  - The Maneuver Team is the CM board for all tools and calibration parameters
- Maneuver Planning & Execution Data
  - implement a file naming protocol as files are promoted through the approval decision flow

Orbit Planning Products

Flight Operations Review

Product	Use	From	To	S/W	Frequency	Span	Format	Notes
Acquisition Data for TDRSS	TDRS contacts for MAP Launch & phasing loops	MMFD	NCC	ADG	As required per Acquisition Data Plan (ADP)	Individual state vectors per ADP	IIRVs	Standard MMFD Function. MMFD will use Orbit State provided by SCT using NAVGSE
DSN Monitor Block Comparison	Match DSN Monitor block angle data with predicted angle data	CGS	SCT	CGS	Per DSN Pass	Real Time	ASIST Page	Use IMAGE flight data to confirm capability
User Antenna Views (UAVs)	Short term pass planning	NAVGSE	MOPSS	STK	weekly	4 weeks or Ephem span.	Standard STK output	Need detailed omni & MGA info into STK
Line of Sight Contact Predicts	Long term planning	NAVGSE	MOPSS	STK	weekly	8 weeks, 1 year	Standard STK output	Can be done now
SPK acquisition data	MAP orbit data for DSN 26,34,70 m contacts	SMOC/FD	JPL MMNAV	STK	weekly	4 weeks	SPICE SPK format	
Orbit vector(s) for OBC	OBC ephemeris propagation	SMOC/FD	MOPSS	STK	weekly	Single Orbit State Vector	Oracle table insert, J2000, ECI, position in m, velocity in m/s	Tested in E-T-E 2
Clock Calibration	Maintain S/C Time	CGS	SCT	CGS	Per DSN Pass	N/A	ASIST Page (Clock Drift Plot and Offset to Uplink)	
Radiation Predicts	Planning for Potential Upsets	NAVGSE	SCT	STK		28 days or less	Standard STK output	Req. for launch & phasing loops; Need environment models
Code 500 Ephemeris, Predicted & Definitive	All Navigation Products	NAVGSE	Internal Use	GTDS		As needed	PC Binary Code 500 format.	

Orbit Planning Products

Product	Use	From	To	S/W	Frequency	Span	Format	Notes
ASCII ephem, Predicted &Definitive	Human readable form for Science , Mission Planning, Archival	NAVGSE	SCT, OMEGA	STK	weekly	1 week definitive, 4 week predictive	ASCII Text, J2000, ECI, position in km, velocity in km/s, scientific notation	
NORAD Brouwer Mean Elements	NORAD	MMFD	NORAD	GTDS				Standard MMFD Function. MMFD will use Orbit State provided by SCT using NAVGSE
Maneuver Planning File	Mnvr commands, Mission Planning	Maneuver Team	SCT	STK-Astrogator	Per Maneuver Schedule	Maneuver Period	CQT; ASCII files with burn information, exact format tbd	CQT tested during Mission Sim 2. Details in work
Maneuver Command Files	To Build Maneuver Command Sequence	SCT	ASIST/MOPSS	CGS	Per Maneuver Schedule	Maneuver Period	CQT, Oracle table insert	Details in work
Comprehensive Trajectory Summary	Mission Planning	NAVGSE	SCT	STK	weekly	8 weeks	Standard STK Trajectory Plots and Tables	
Lighting Predicts (Illumination percentage, Earth & Moon Umbra & Penumbra times)	Mission Planning	NAVGSE	MOPSS	STK		8 weeks	Oracle table insert	
Propulsion and ACS Maneuver tlm Real Time & Recorder	Maneuver monitoring & Maneuver reconstruction/calibration	CGS	Maneuver Team	CGS	Per Maneuver Schedule	> Maneuver Span	Seq. Print Files, IDL Plots	Details in work

Orbit Planning Products

Flight Operations Review

Product	Use	From	To	S/W	Frequency	Span	Format	Notes
OBC ephemeris from tlm, Real Time & Recorder	Ephemeris verification	CGS	SCT	CGS			MTASS Ephemeris Comparison Report	
OBC attitude from tlm, Real Time and Recorder	ACS monitoring & calibration	CGS	SCT/ACS	CGS	Per Pass	Available Data Span	Seq. Print Files, MTASS AHF	
Attitude History File from ground processing of Real Time and Recorder	ACS monitoring & calibration	NAVGSE	SCT/ACS	MTASS	Per Pass	Available Data Span	MTASS AHF	
Orbit State vector	Orbit Determination, Maneuver Planning & Calibration	NAVGSE	Trajectory Design Team	GTDS	Per Maneuver Schedule, otherwise weekly	1 Orbit State Vector	ASCII Text, J2000, ECI, position in km, velocity in km/s, scientific notation	

Ground System Autonomy
SSR Management
Clock Correlation

Peter Gonzales

Taking MOPSS to the next Level

MOPSS

- Mission Operations Planning and Scheduling System (MOPSS)
  - MOPSS is a graphical planning and scheduling tool
  - ORACLE database is employed to store all MOPSS data
  - Initial schedule generation is generally performed offline
  - Has capability to reschedule activities in real-time
  - Capable of starting ASIST procedures based on the timeline and/or contingent upon the success of preceding procedures

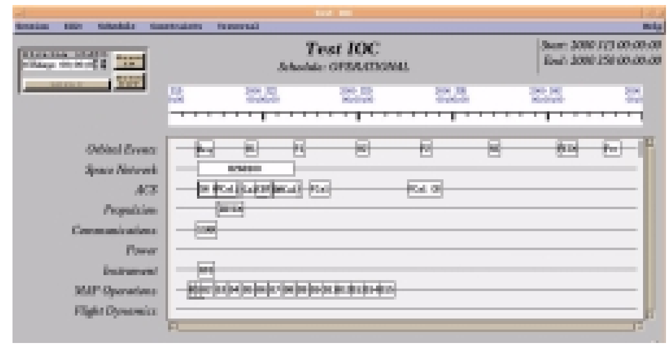
- MOPSS during I&T
  - Provides a comprehensive plan of extended test activities
  - Will run in monitor mode for most tests, displaying the success/failure status of test milestones as they are completed

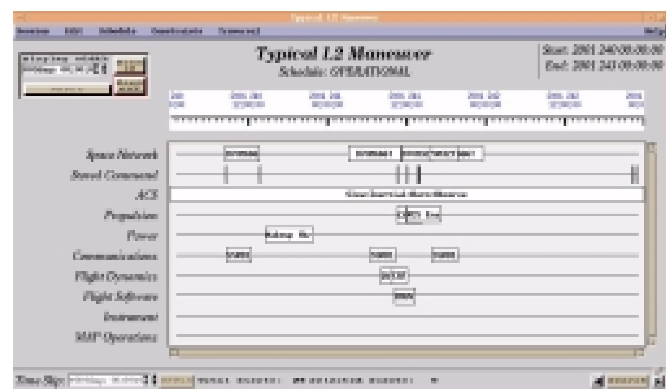
MOPSS (cont.)

- MOPSS during Mission Operations
  - Inputs used to create real-time and stored command sequences based on user input constraints
  - Outputs a scheduled timeline for nominal pass activities

MAP and MOPSS

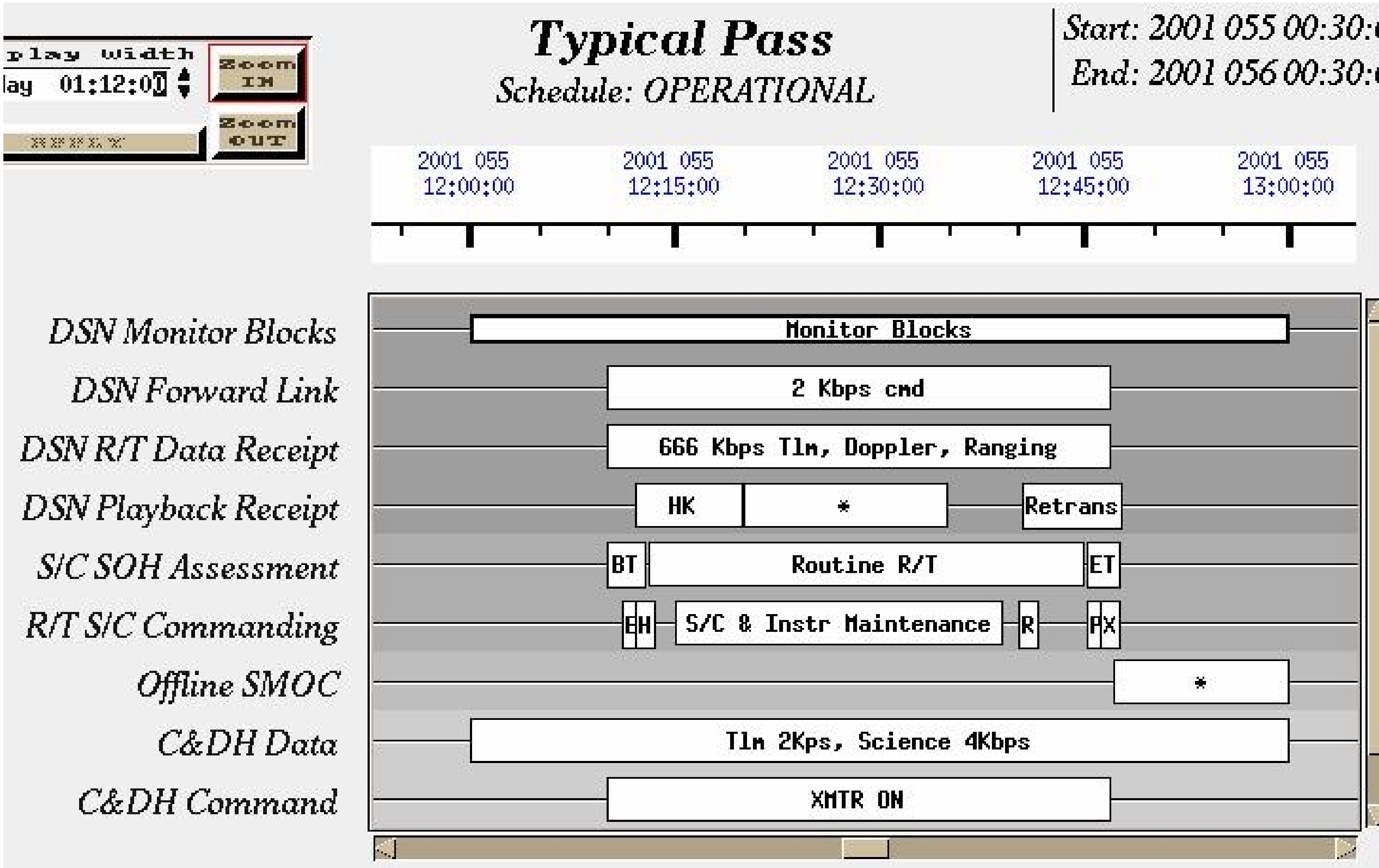
- MAP is the first to use MOPSS
  - For both R/T & Stored Cmd planning
  - For ultra long term planning
  - To support Lights Out Operations
  - To support MAP in monitor mode during IOC
  - To support Spacecraft I&T
  - To interface with ASIST





MOPSS Timeline for Nominal L2 Pass

Flight Operations Review



MAP Ground Autonomy

Ground System Automation Elements

- The following elements combine to form the MAP automated ground system
  - FEDS/ASIST:
    - Baseline real-time operations ground system
    - Primary command/telemetry interface between the control center and spacecraft
    - Performs decommutation of telemetry and command generation
    - Executes STOL procedures
    - Performs real-time playback trending
  - MOPSS
    - Graphical planning and scheduling tool
    - Schedule baseline pass activities based on user defined constraints
    - Pass schedule is transmitted to the ground system for execution
    - Will be used to create real-time and stored command sequences

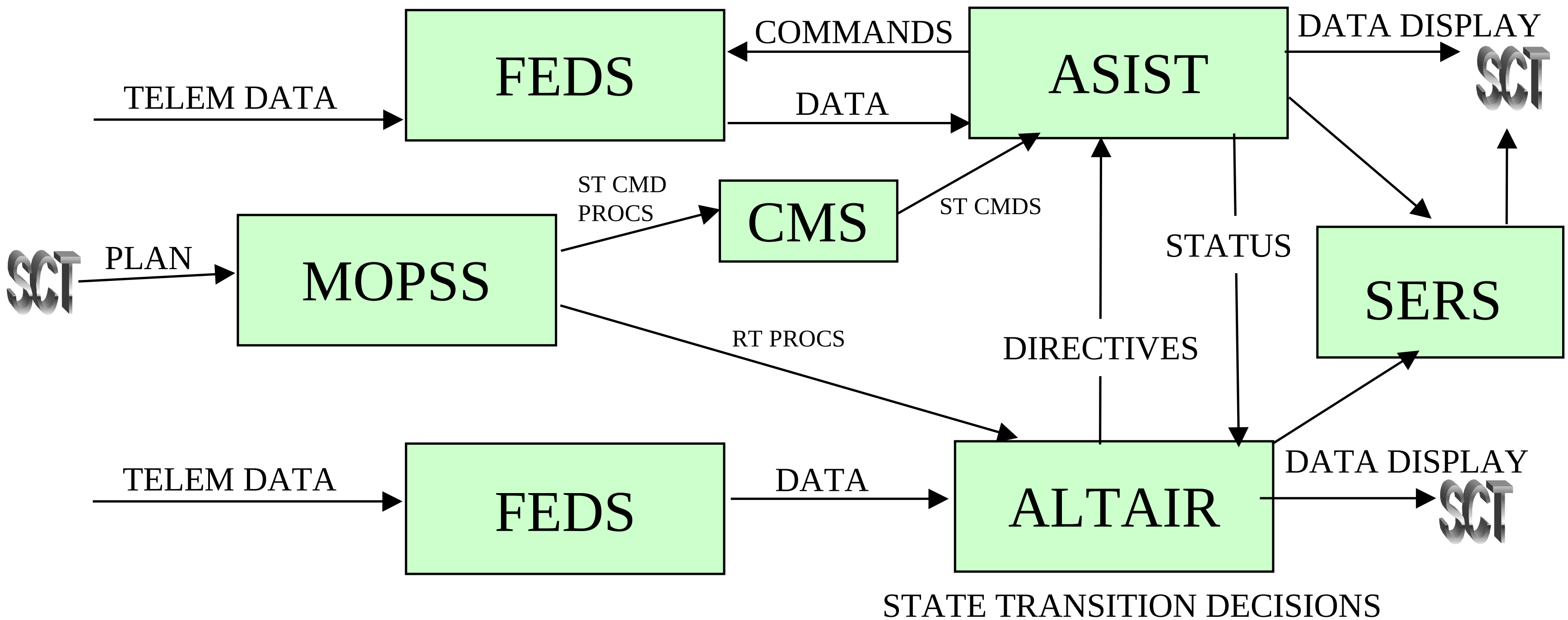
Ground System Automation Elements (cont.)

- Altair:
  - Expert system based on state modeling tool
  - Will contain state models of the spacecraft and ground systems.
  - Can conduct nominal operations based on MOPSS schedule
  - Interfaces with ASIST to start and then monitor STOL procedures
  - Can detect and correct anomalous conditions
    - Ex. Can send an email to the SERS when a spacecraft anomaly or ground system misconfiguration is detected

Ground System Automation Elements (cont.)

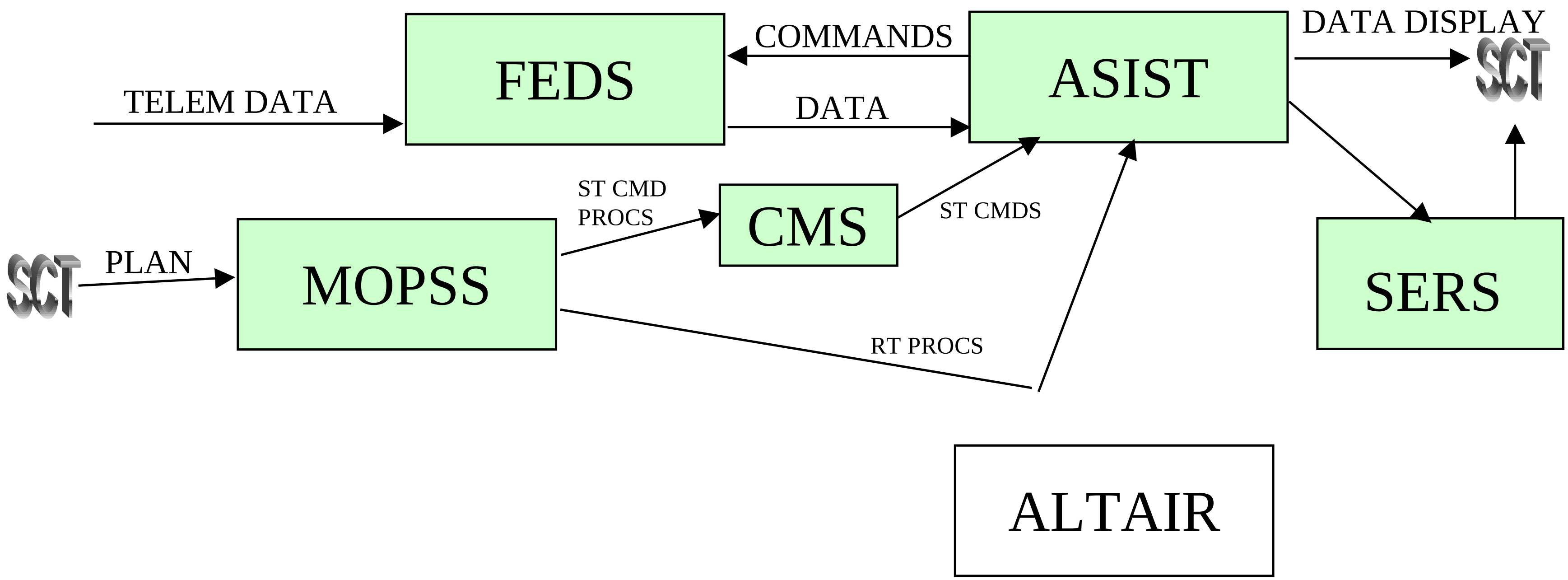
- SERS:
  - Emergency response tool based on a database driven emergency response system
  - Accepts formatted email as the notification of an event requiring a page be sent
  - Contains cross-reference between failure types and responsible engineer rosters
  - Will page responsible engineer(s) based on failure scenario(s) in a priority sequence
  - Sends alphanumeric message containing the failure description to the pager
  - Can control responsible engineer rosters and frequency of pages sent
  - Will produce an anomaly report

Ground System Configuration - Autonomous



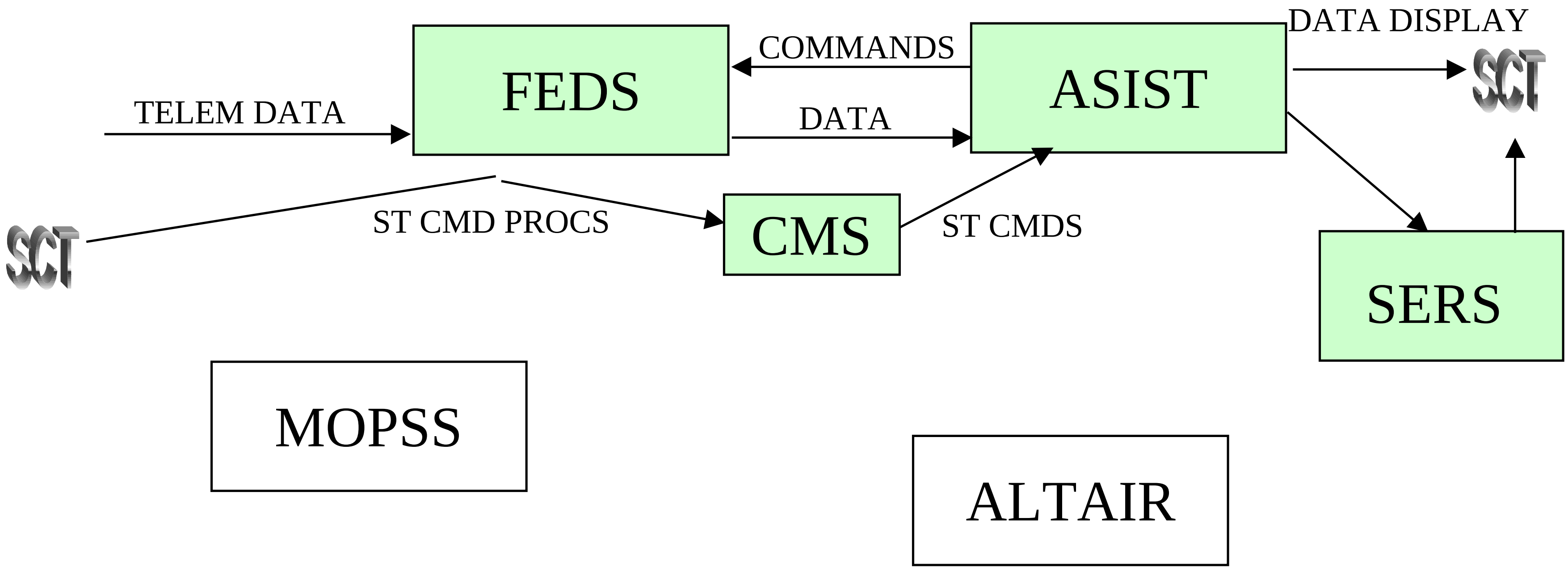
This is the planned operational mode. Two other modes will be tested and available as backups to mitigate the risk of new technology.

Ground System Configuration - Automated



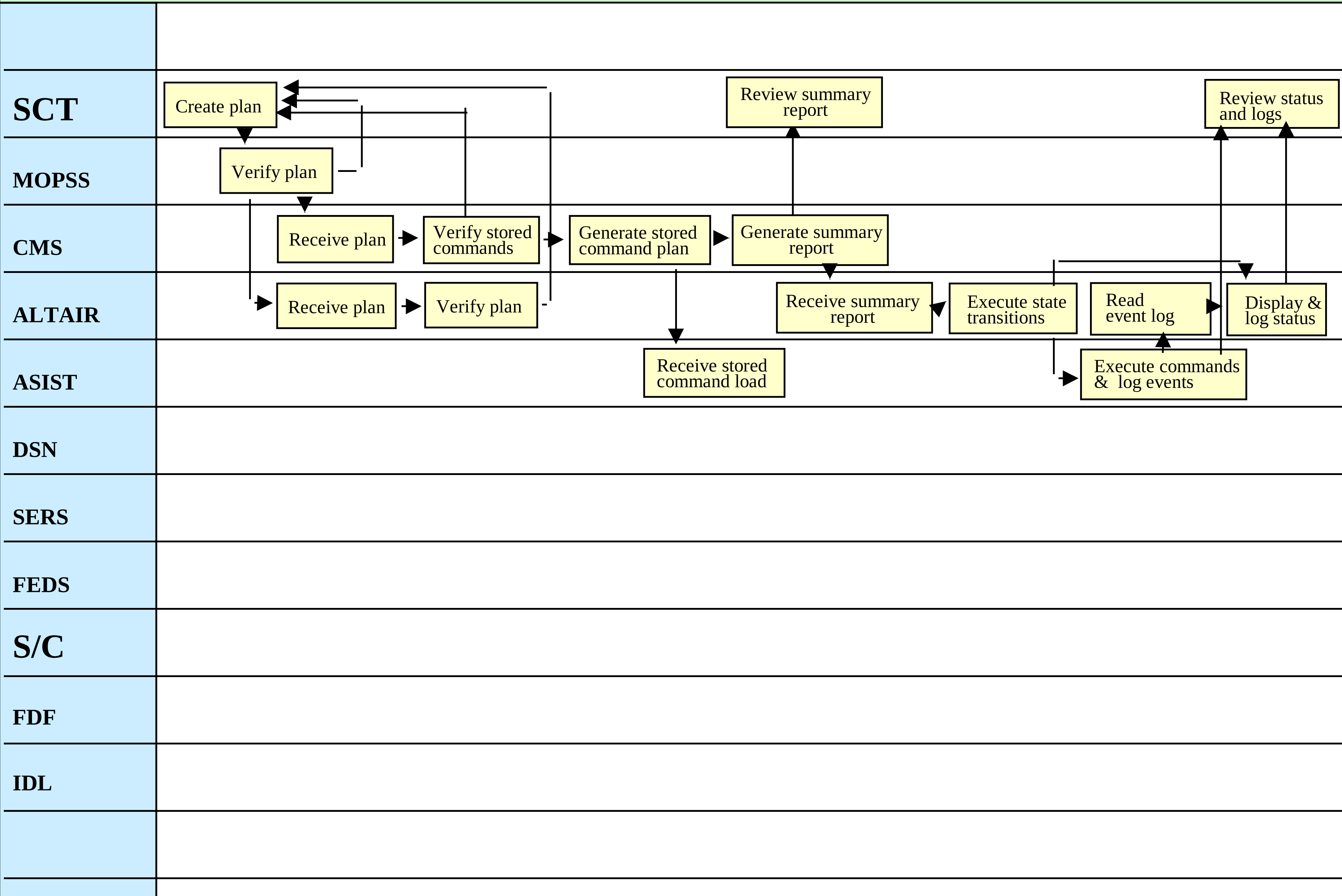
Impact: State modeling and intelligent decision making are not available

Ground System Configuration - Manual

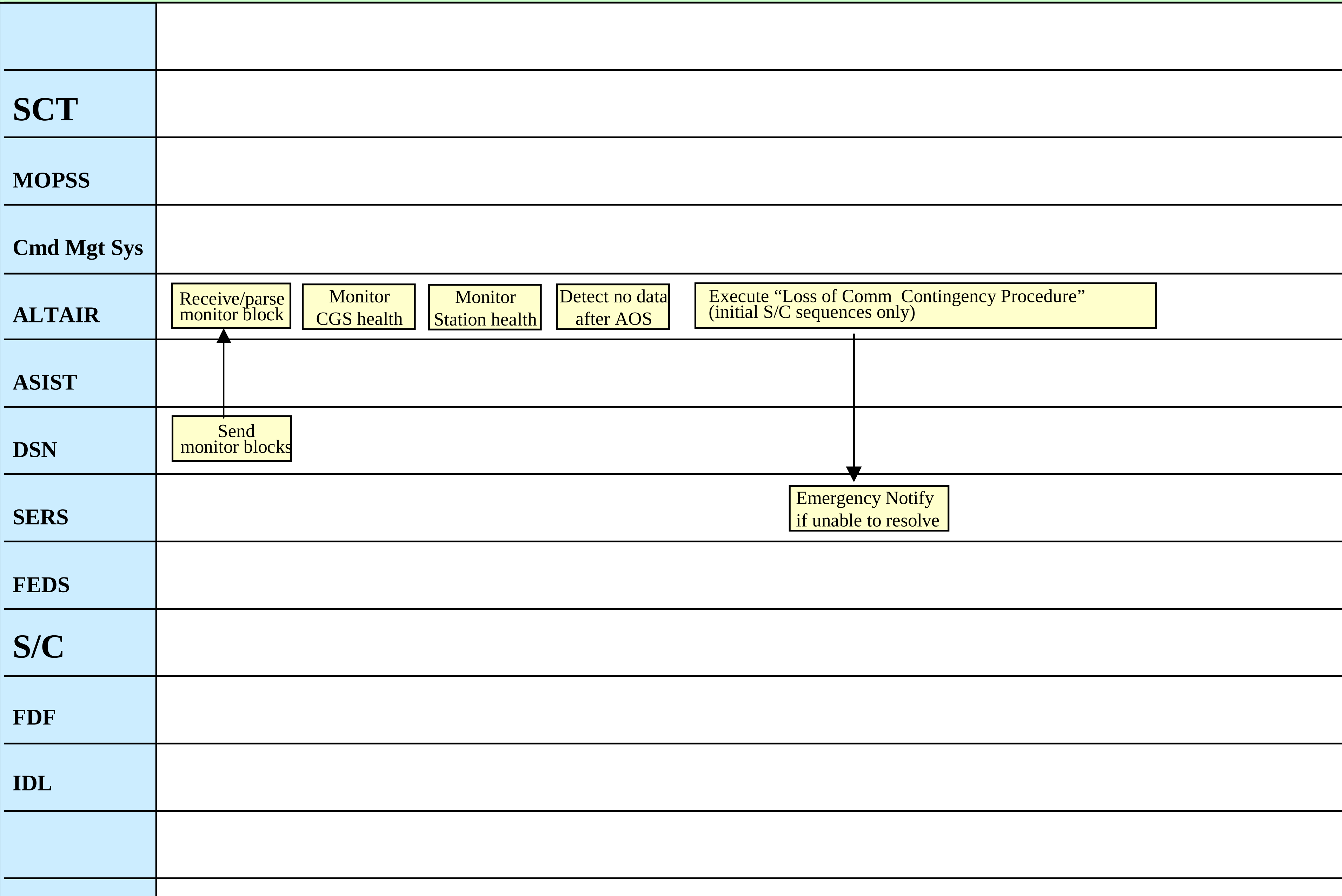


Impact: SCT needed to command and control spacecraft

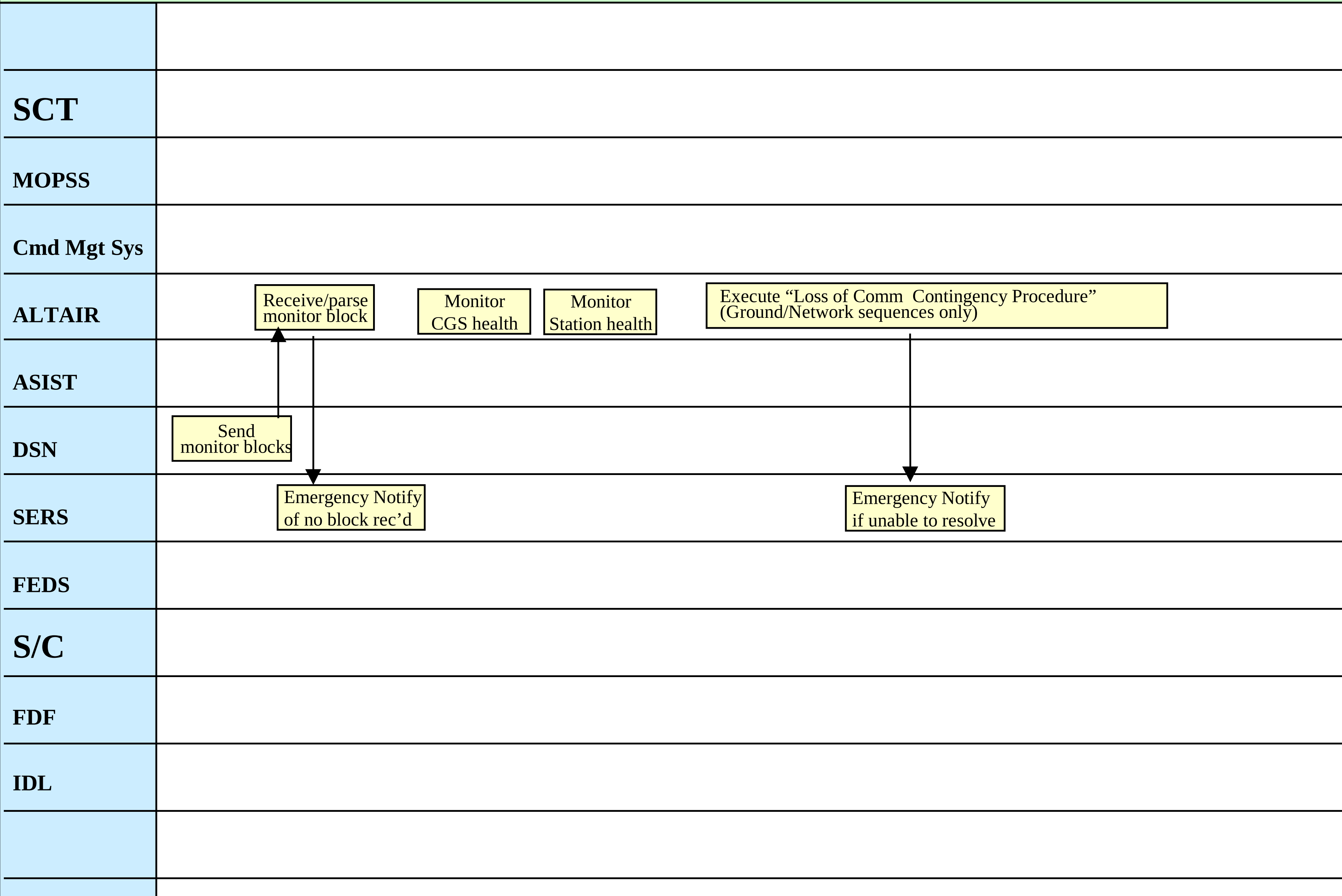
1. Generate Plan and Perform Nominal Commanding



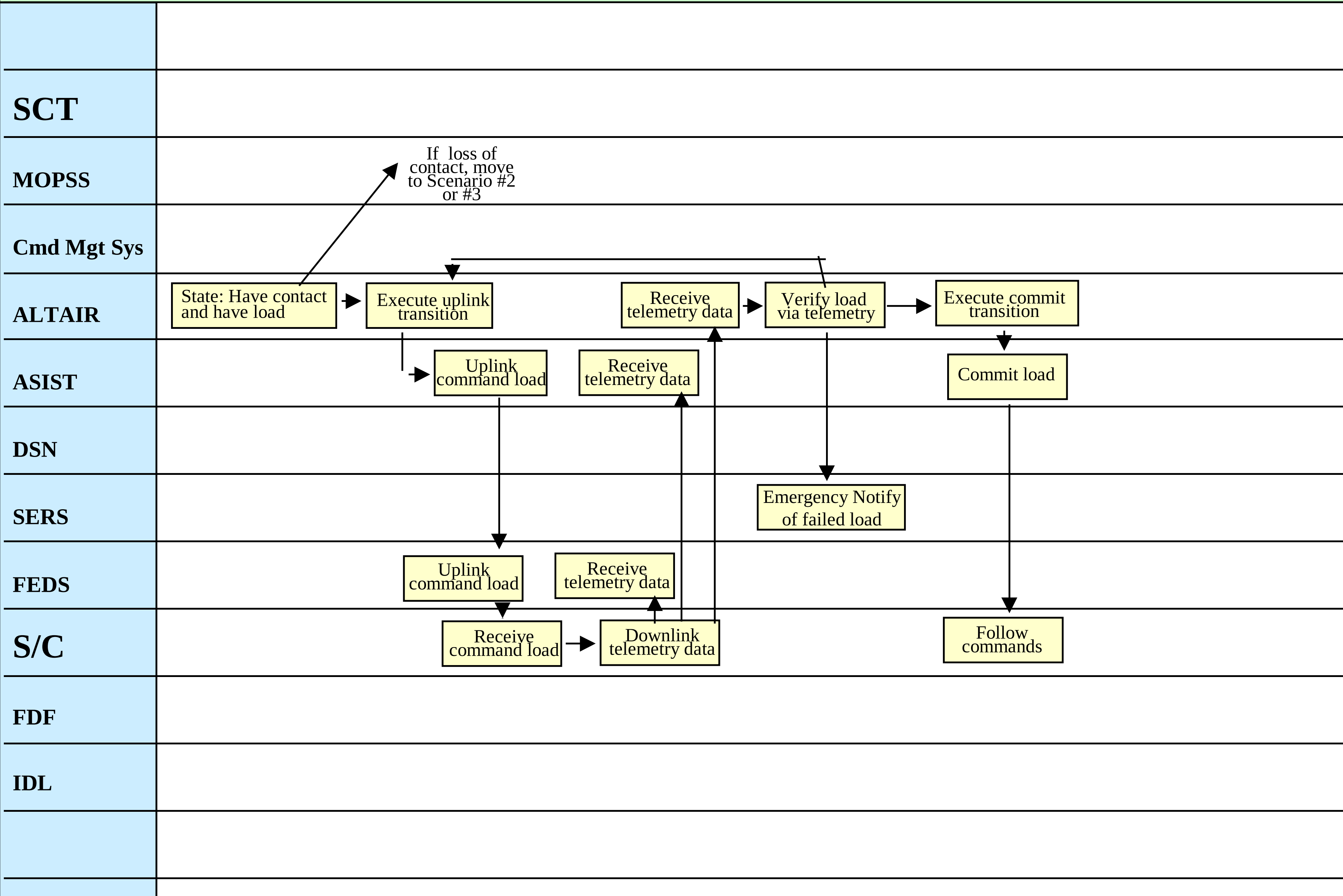
2. Detect and Handle Spacecraft Comm Problem



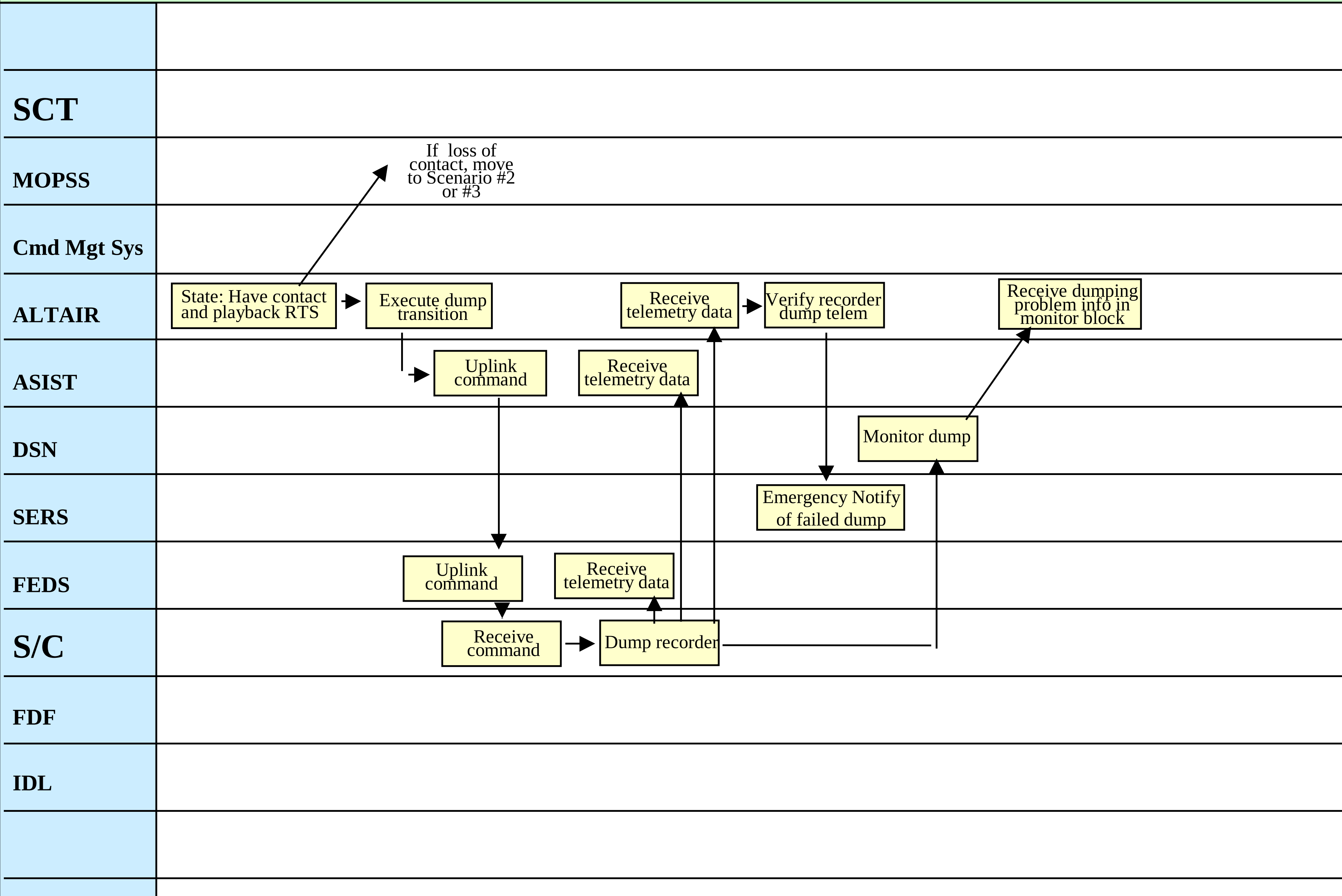
3. Detect and Handle Ground Comm Problem



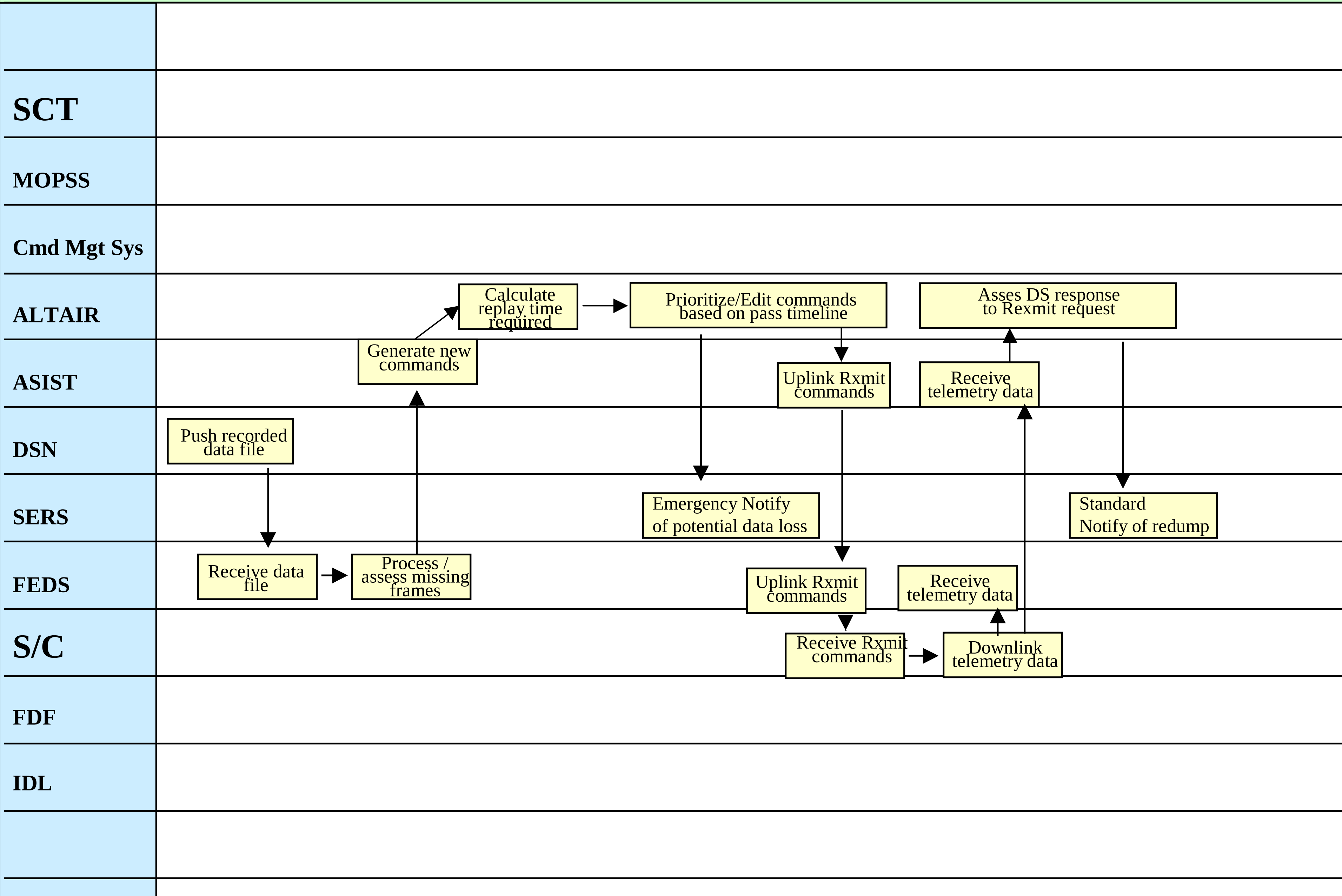
4. Uplink Stored Command Load



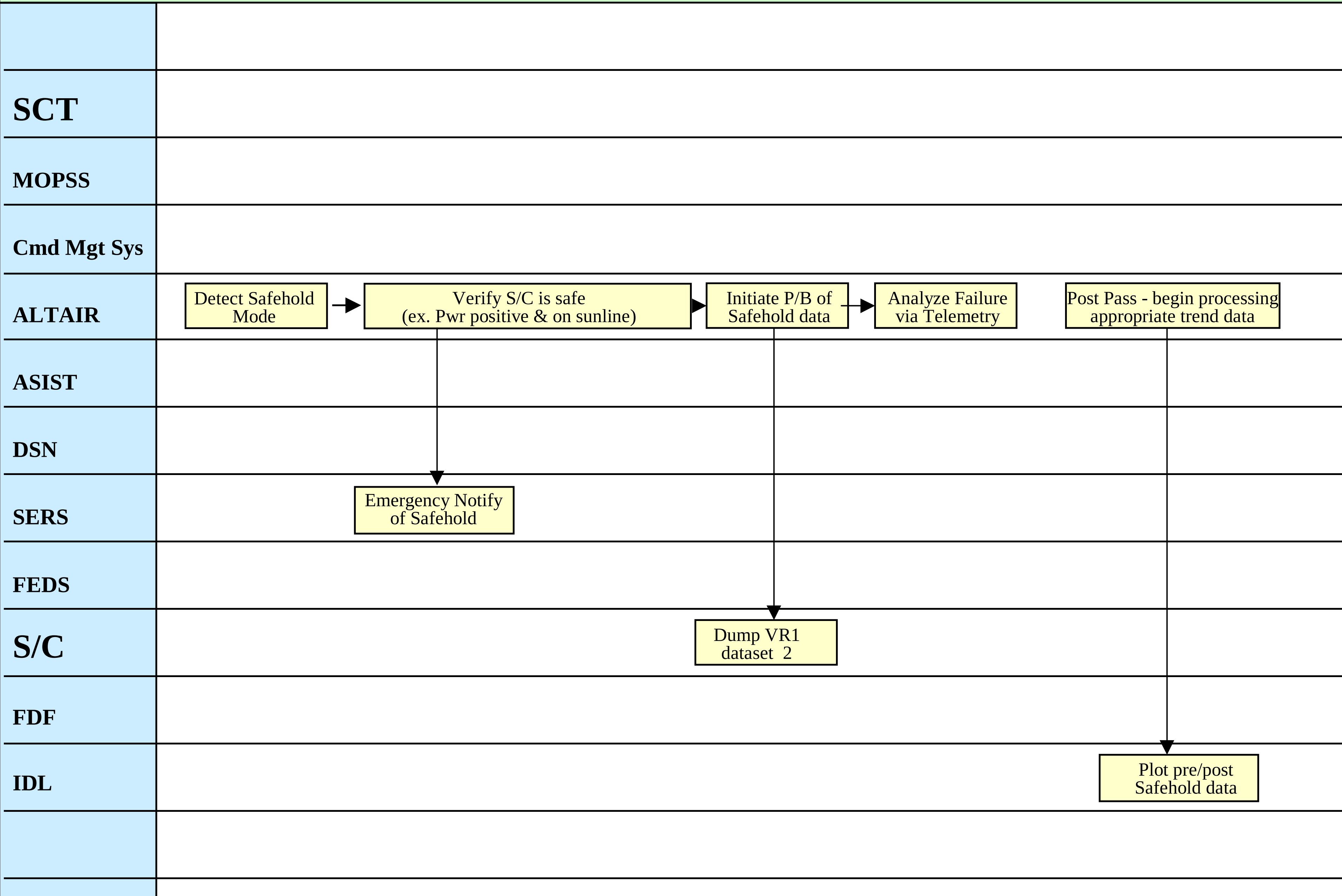
5. Initiate Solid State Recorder Playback



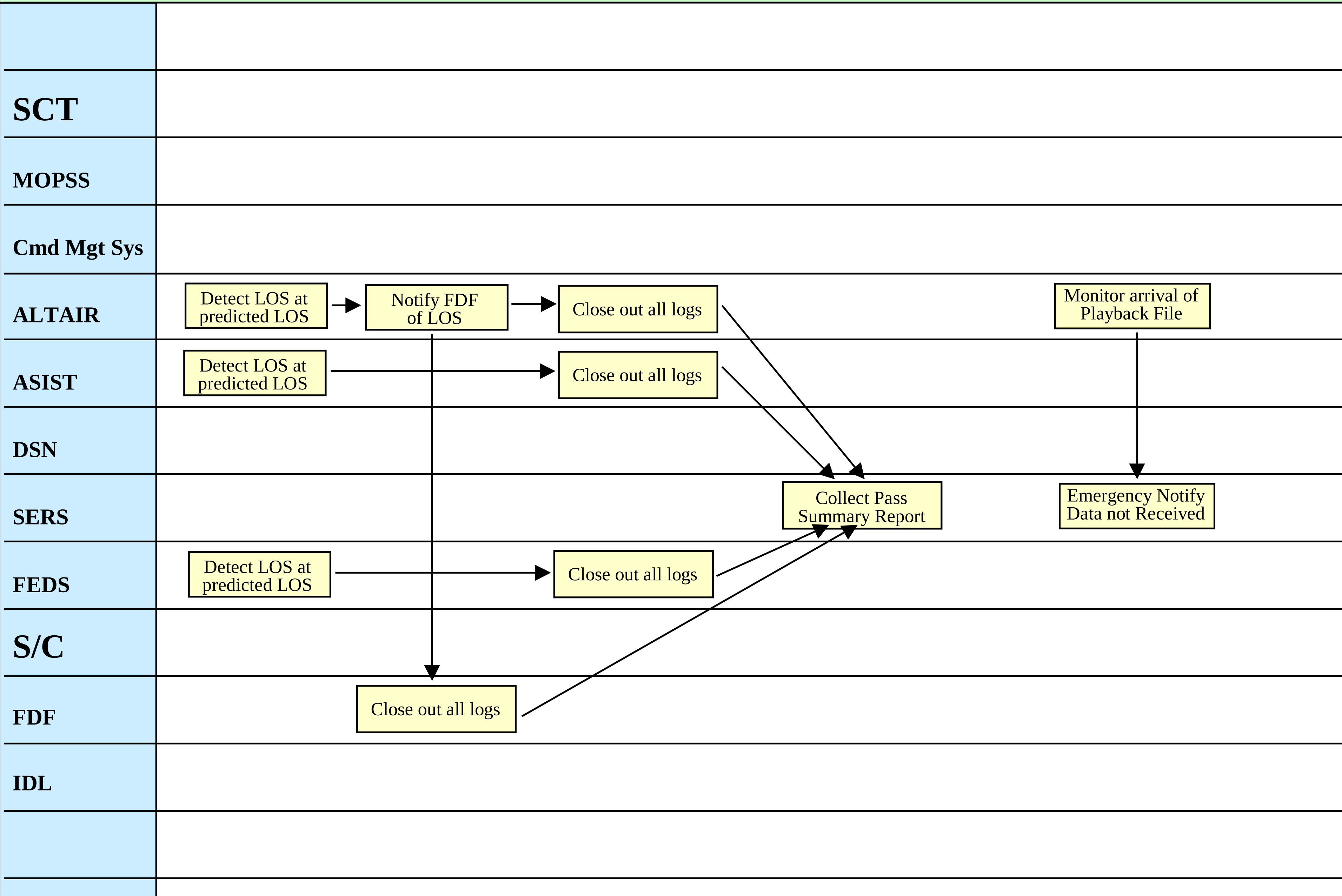
6. Receive Recorded Telemetry and Redump Missing Frames



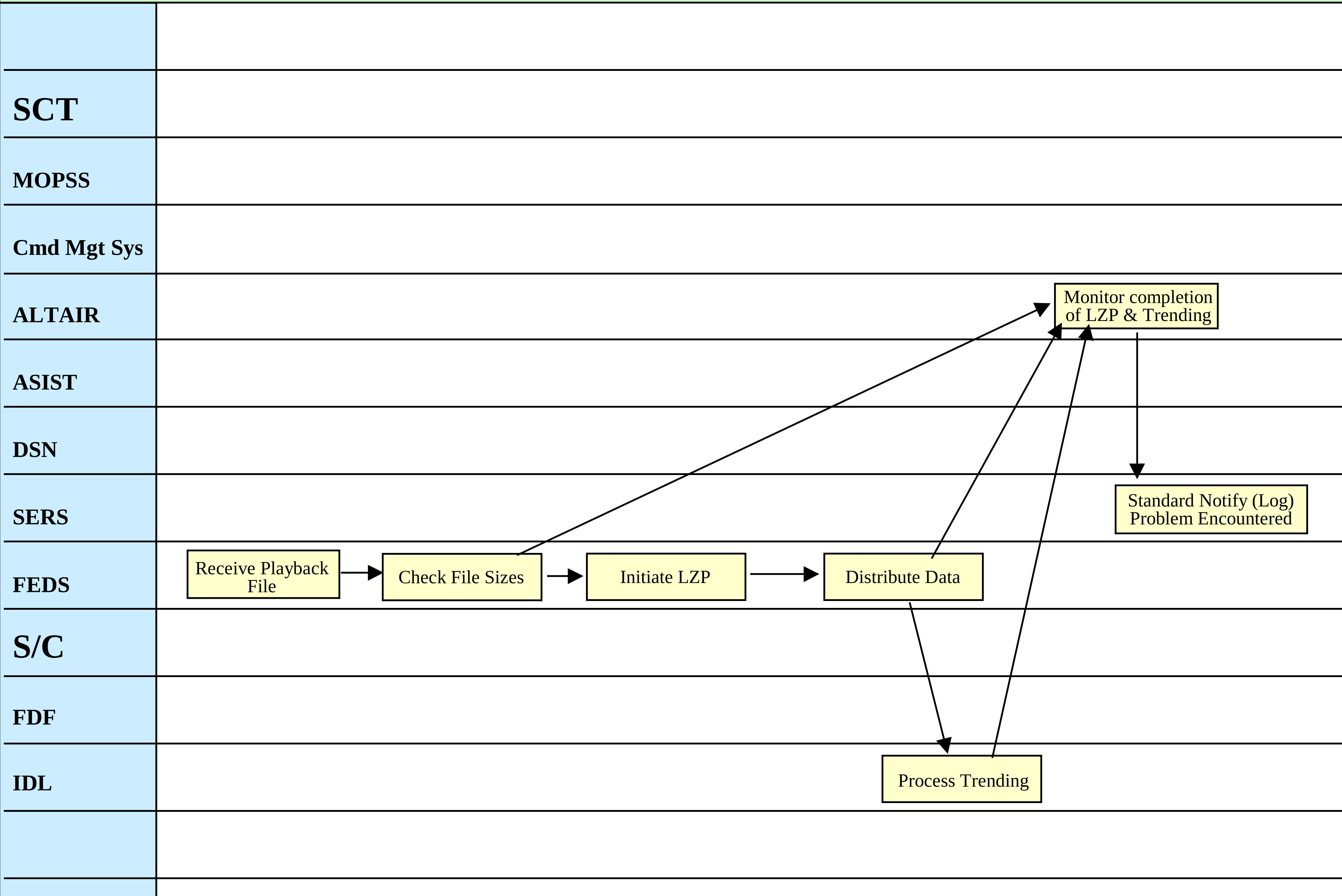
7. Observatory is in Safehold Mode



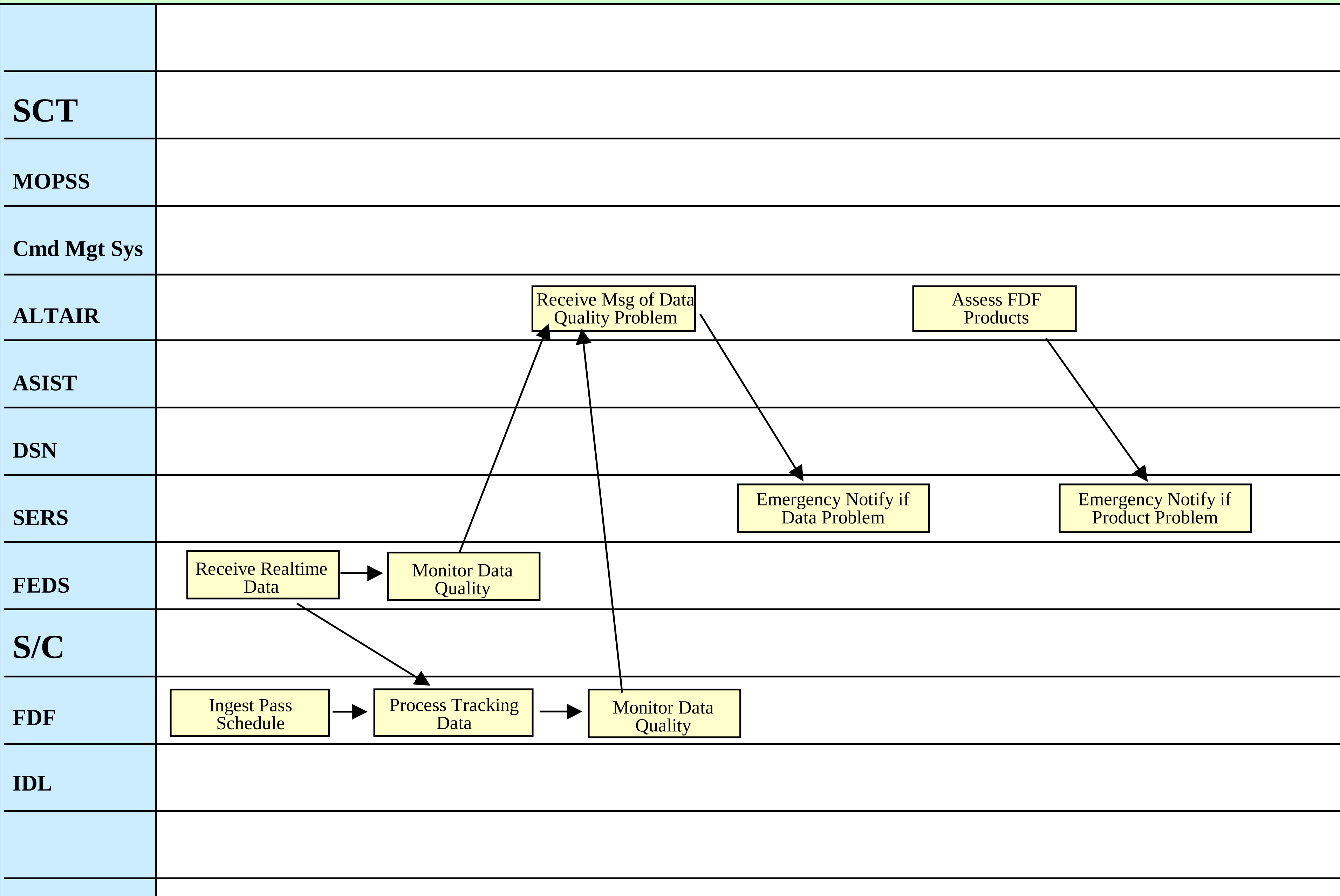
8. Post Pass Closeout



9. Data Processing, Distribution, and Display



10. FDF Processing



Additional Automated Ground System Scenarios

- Automatic Archival
  - File archival , including file transfers (ex. to the DHDS) and file maintenance will be performed by Altair. Files may be required to be transferred from the closed net to the open net. Files requiring automated control are still TBD.

- Automatic Report Generation
  - All systems will be made to generate summary reports. The SERS will collate reports (such as the Pass Summary Report) for Web posting. Report contents and formats are still TBD.

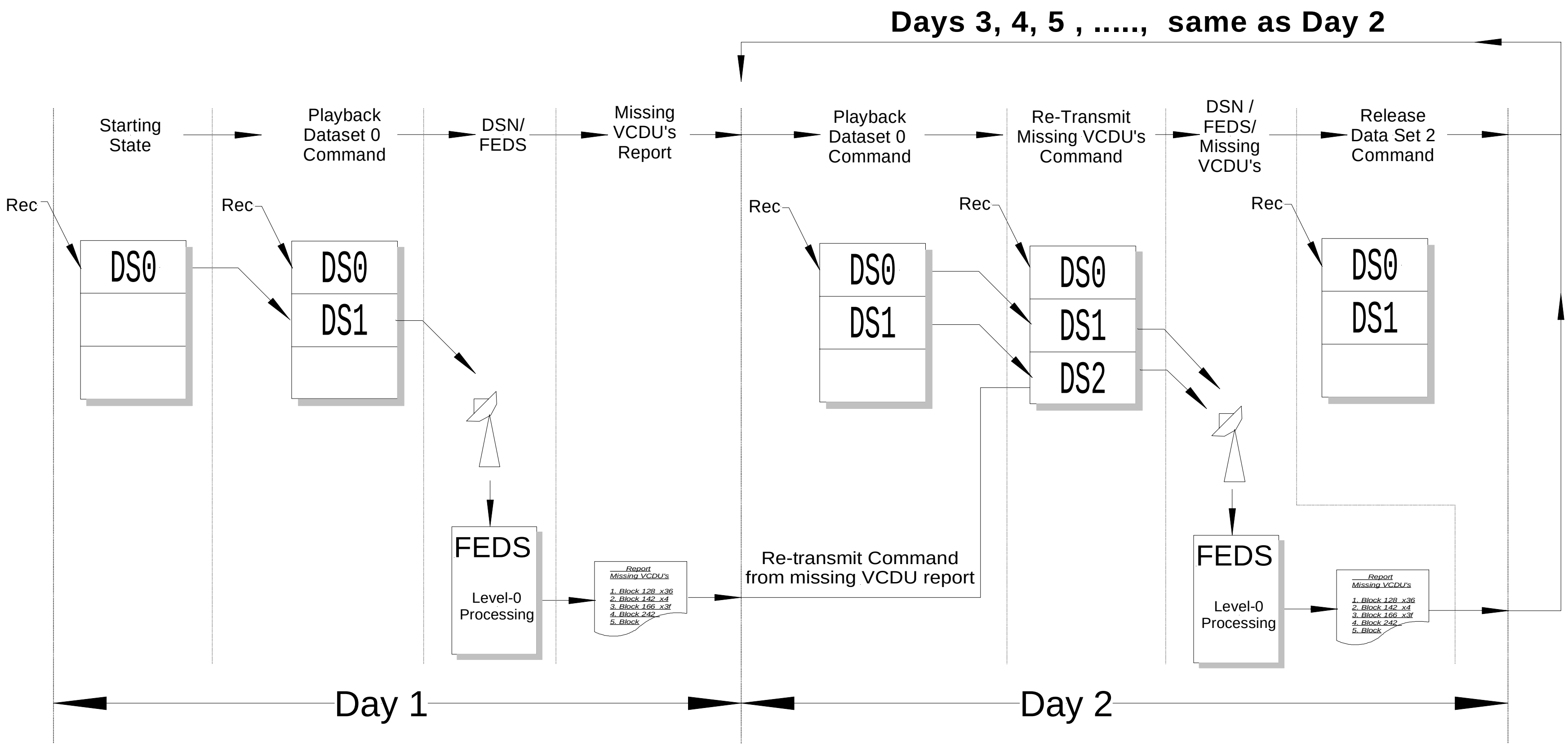
- Spacecraft Health and Safety Analysis
  - Altair will be responsible for monitoring anomalous spacecraft states and alerting operators via the SERS.

Automated Ops Transition Plan

- Pre-launch
  - Perform E-T-E Tests and normal ops portions of the Mission Sims in Auto Mode
  - FlatSat will provide high fidelity testbed for Auto
  - On “best effort bases” run all Mission Sims in parallel monitor mode
  - Auto Tools available for use in CPT’s
- Post-Launch
  - Auto Tools run in “shadow mode” during cruise
  - As confidence is gained, transition to Auto Mode at L2

Solid State Recorder
Daily Operations

Flight Operations Review



Solid State Recorder Operations

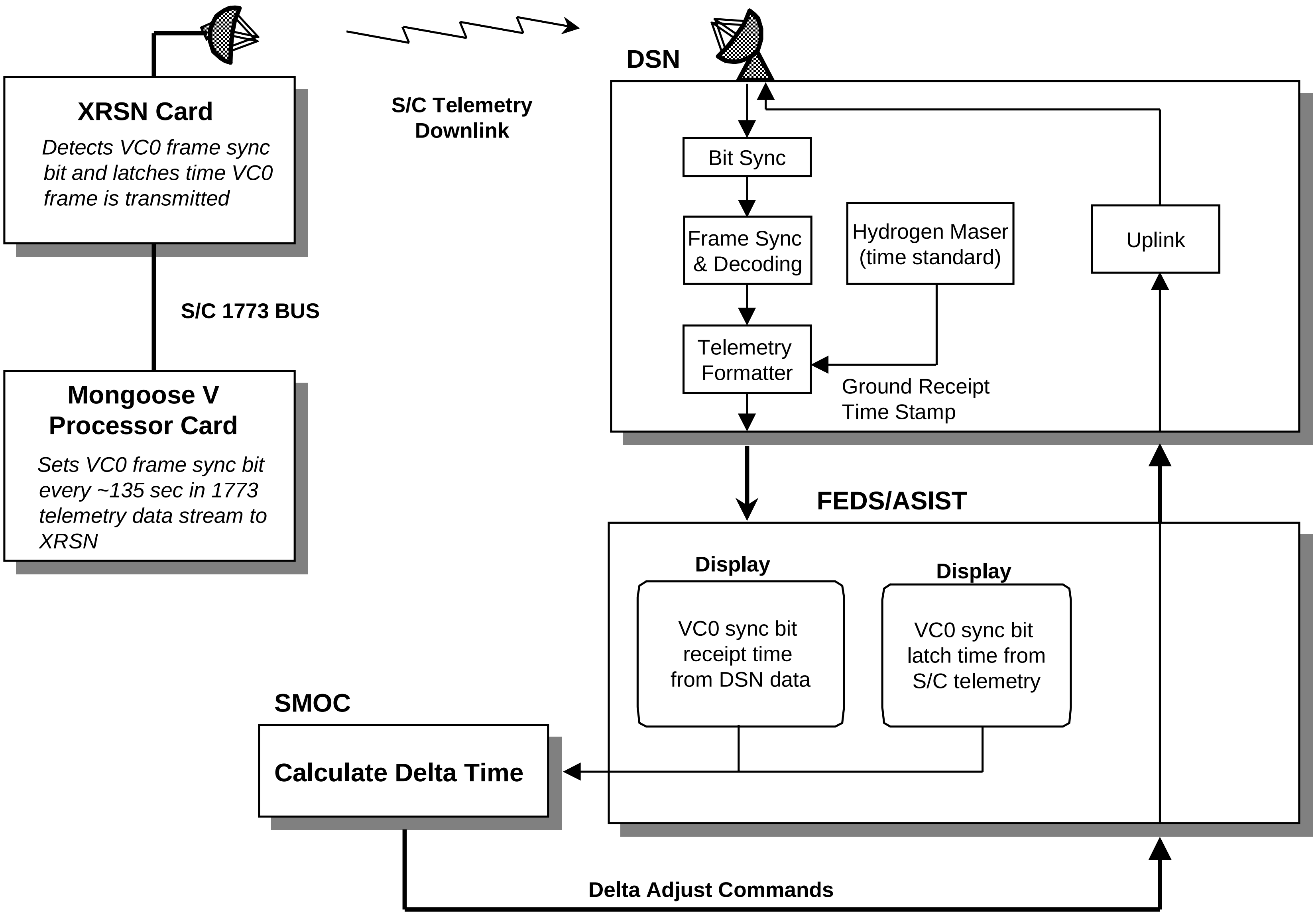
- Scheduled 37 minute pass daily. Recorder sized for 2 days
- Daily dumps done @ 666Kb downlink rate; est. ~ 23minutes (1 day's worth of data)
- SSR memory divided into 3 Virtual Recorders (VR's)
  - VR#1 Spacecraft & Instrument Housekeeping 100Mb
  - VR#2 Spacecraft Events 85Kb
  - VR#3 Science 130Mb
- VR#1 & #2 operate in non-overwrite mode; VR#3 operates in overwrite mode
- Default priority of recorders from highest to lowest is VR#1, VR#2, VR#3
- VR's are defined by an onboard segment table and are modifiable in flight via a software table load.
- The CCSDS packet storage filter factors are configurable in an onboard system table.

Recorder Playback Accounting

- Recorder data stored at DSN
- DSN CDR initiates FTP of playback data to SMOC
- SMOC accounts for all VCDU frames
  - FEDS in SMOC runs data file through level-0 processing
    - Data time ordered, duplicate packets thrown out
    - FEDS outputs list of missing VCDU's
  - Missing VCDU's will be re-transmitted during next pass
    - Will release dataset following re-transmit command
  - Data capture requirement – 90%
  - Data capture goal – 100%

MAP Spacecraft Clock Operations

Flight Operations Review



Spacecraft Clock Maintenance

- Clock Maintenance Requirement (Ground vs. Spacecraft) : ± 1 second
- Using Return Data Delay (RDD) method through the DSN only
- Clock Delta =

$$\underbrace{\textbf{ground receipt time}}_{\textit{DSN time stamp}} - \underbrace{\textbf{range delay}}_{\textit{based on predicted ephemeris}} - \underbrace{\textbf{ground delay}}_{\textit{fixed (per DSN station)}} - \underbrace{\textbf{s/c internal delay}}_{\textit{fixed (calculated during I\&T)}} - \underbrace{\textbf{s/c time}}_{\textit{appid 16 (XA) or appid 17 (XB)}}$$

Spacecraft Clock Maintenance

- S/C Time (in UTC) = Mission Elapsed Time (MET) + Universal Time Correlation Factor (UTCF) + Mission Epoch

- Adjustments to S/C time are made by adjusting UTCF
  - Large clock adjust made by loading new UTCF
  - Clock adjust < ±2 milliseconds by using UTCF adjust command
  - Leap second adjust via leap second adjust command
  - Once oscillator drift is characterized, the 1hz auto adjust UTCF command will be used to compensate for the drift

OMEGA Operations

Gary Hinshaw
Goddard Space Flight Center

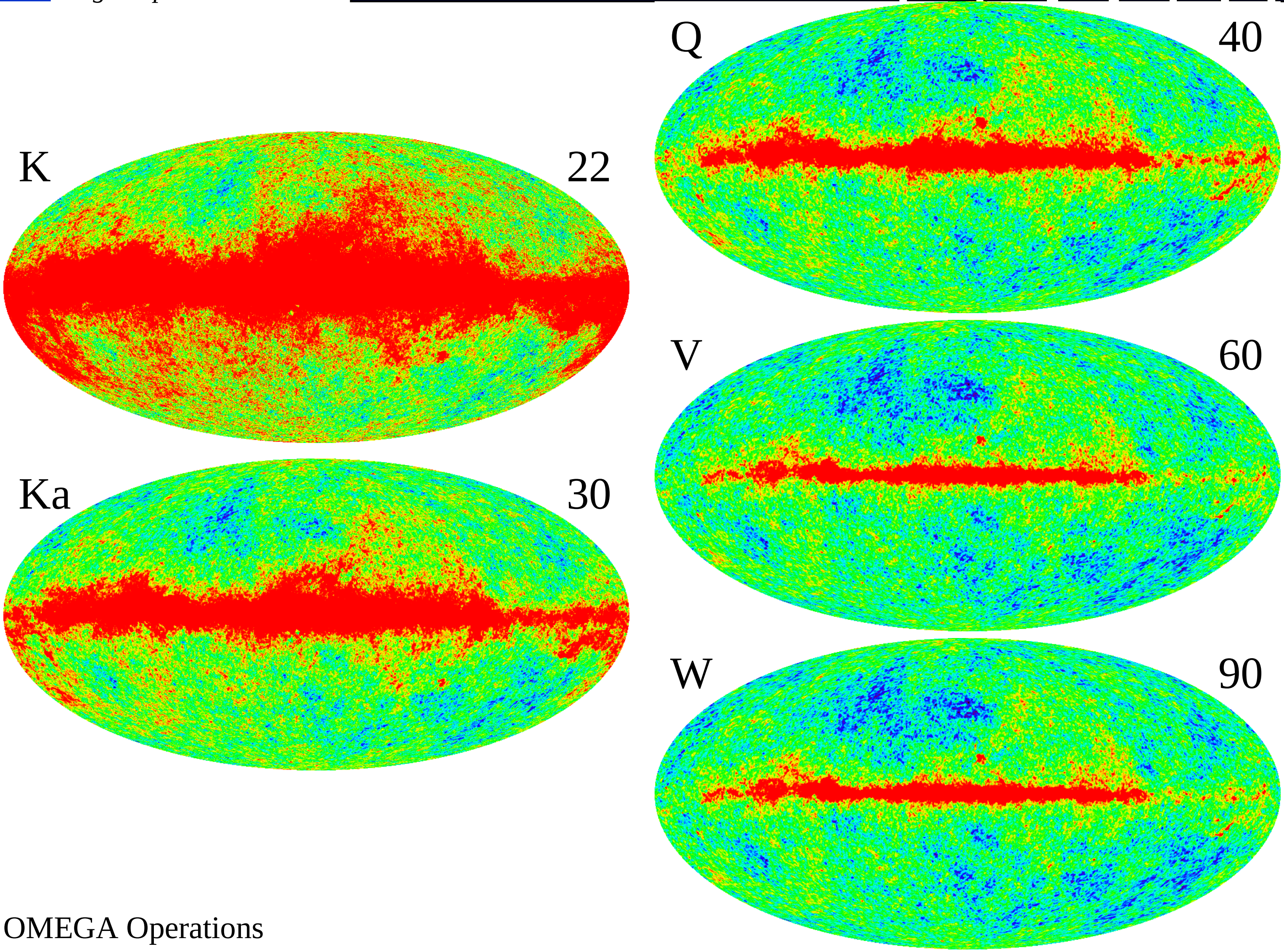
Role of OMEGA

- “OMEGA”: ***O***ffice of the ***M***AP ***E***xperiment ***G***eneral ***A***rchive
- Data analysis only, no mission operations responsibility
- Support I&T data analysis
- Develop and maintain MAP Science Data Archive during the life of the mission
- Write and maintain science data processing software
- Produce and verify calibrated sky maps and ancillary data
  - Analyze maps for systematic errors - the *heart* of the job
- Deliver calibrated and corrected maps and ancillary data to NSSDC for public dissemination

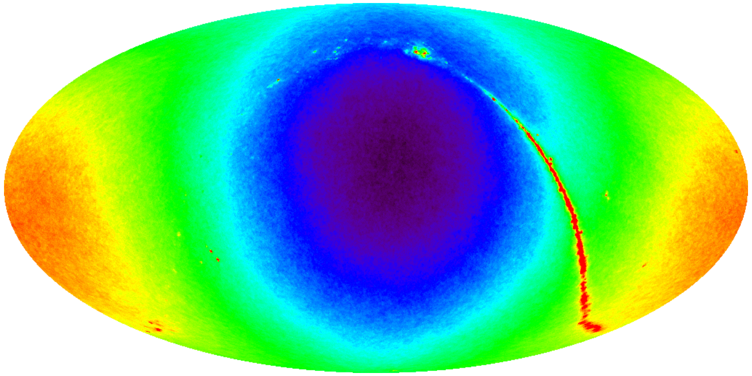
Science Data Products

- 30 calibrated sky maps of CMB anisotropy
  - 3 maps for each of 10 DAs
    - 3 maps: 1 temperature and 2 polarization (Stokes: I, Q, U)
    - 10 DAs: 1 @ 22 GHz (K), 1 @ 30 GHz (Ka), 2 @ 40 GHz (Q), 2 @ 60 GHz (V), 4 @ 90 GHz (W)
  - ~1-2 million pixels per map
- Master archive of temperature differences
  - ~35 GB of data per year
- Ancillary data sets for each differencing assembly
  - Beam response (“window function”)
  - Calibration and offset for each differencing assembly

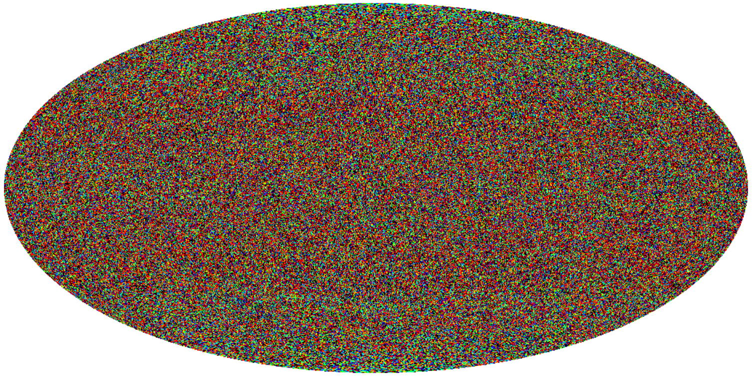
MAP Frequency Coverage: 22 - 90 GHz



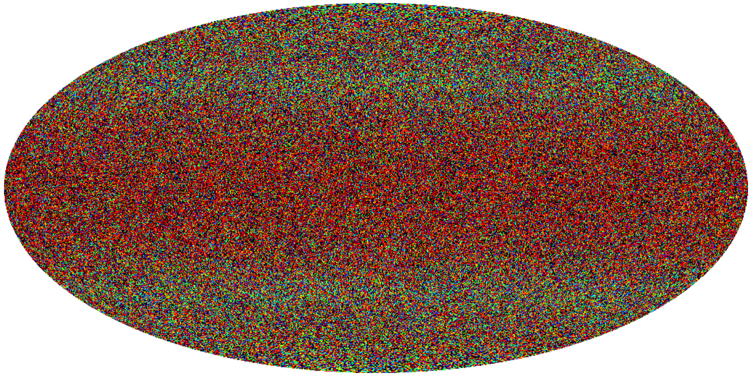
3 Maps from each Differencing Assembly



I



Q



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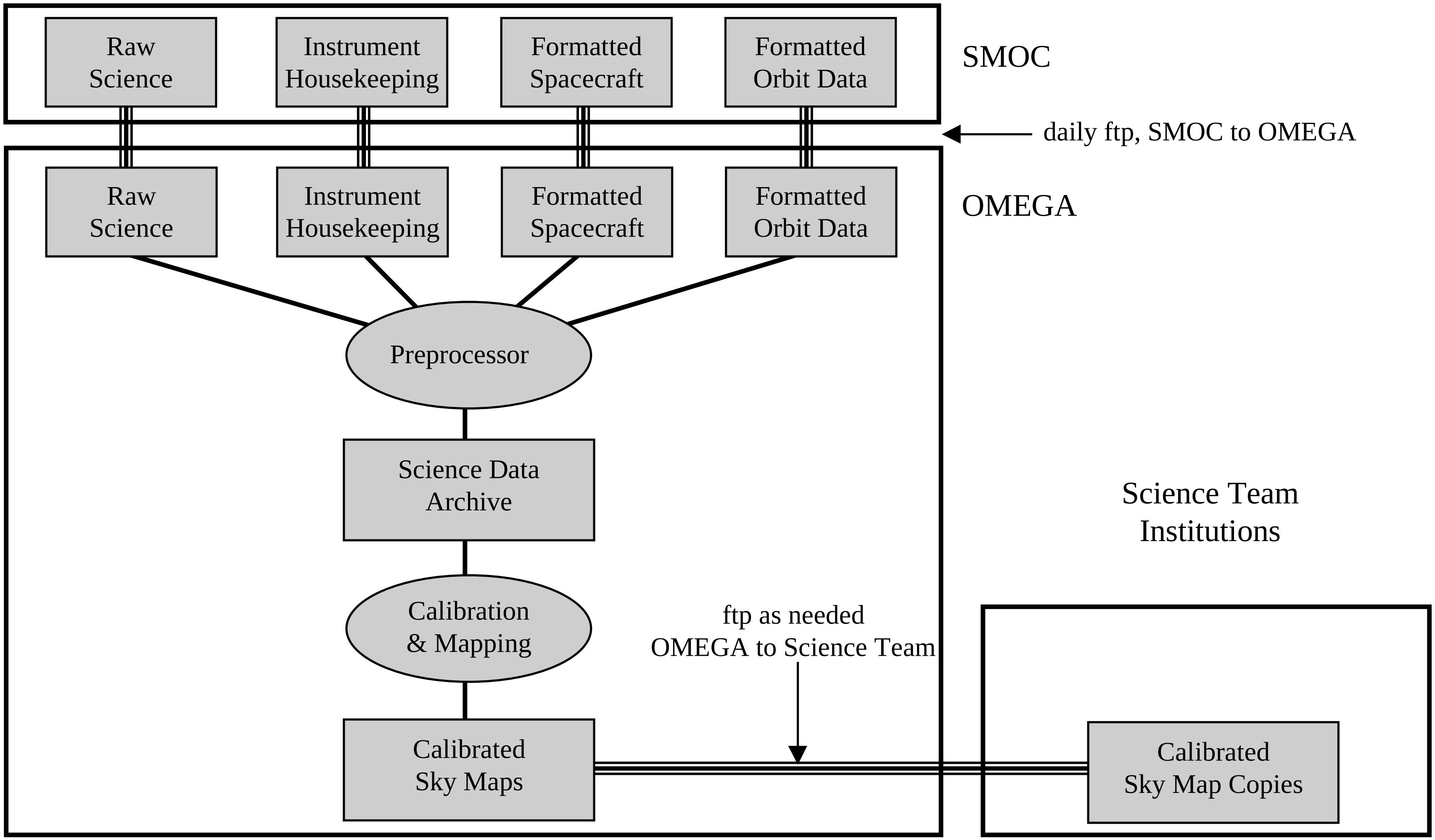
OMEGA- Hardware

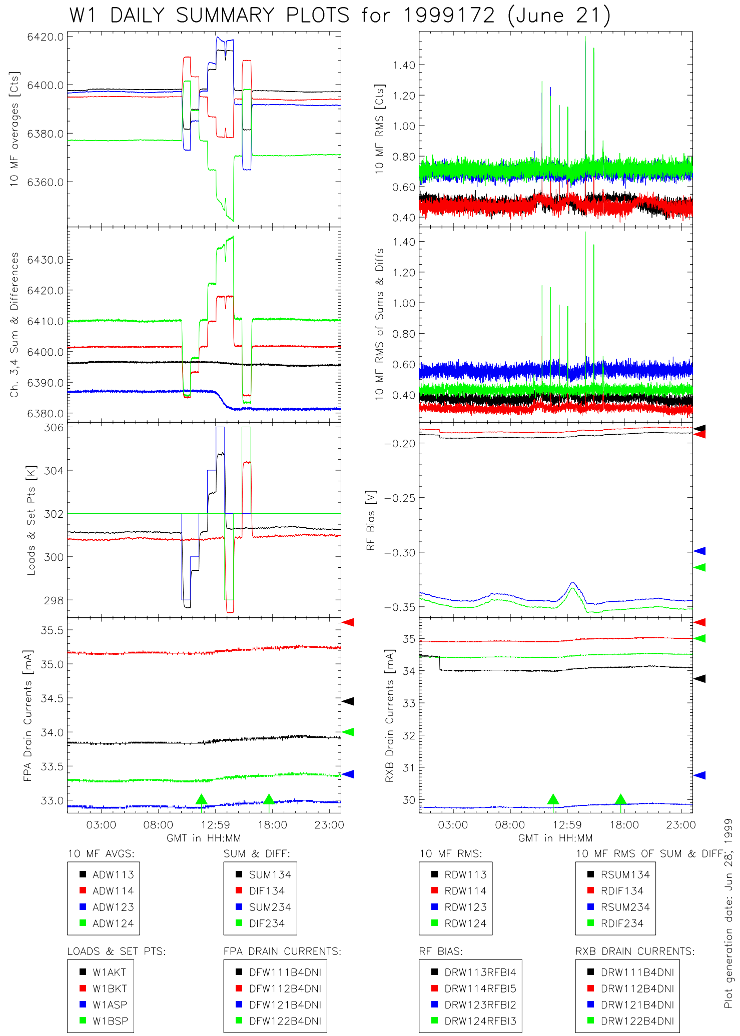
- The computer hardware required to process the MAP flight data will be a mix of inherited COBE systems and newly purchased systems. It includes:
  - DEC Alpha 4100 server w/ ~250 GB disk space (COBE, in place)
  - SGI Origins 2000 server w/ ~600 GB disk space (MAP, installed 1/2000)
  - Intel-based “Beowulf parallel supercomputer” (MAP, Fall 2000)
- The SGI system will provide adequate cpu, memory and disk resources for the core data processing.

Science Data Flow



I&T and Flight Data Monitoring

Flight Operations Review



After data is transferred from SMOC to OMEGA a series of IDL procedures automatically:

1) Generate web page displays and archival Postscript plots of all science and instrument housekeeping signals.
A sample page display is show at left.

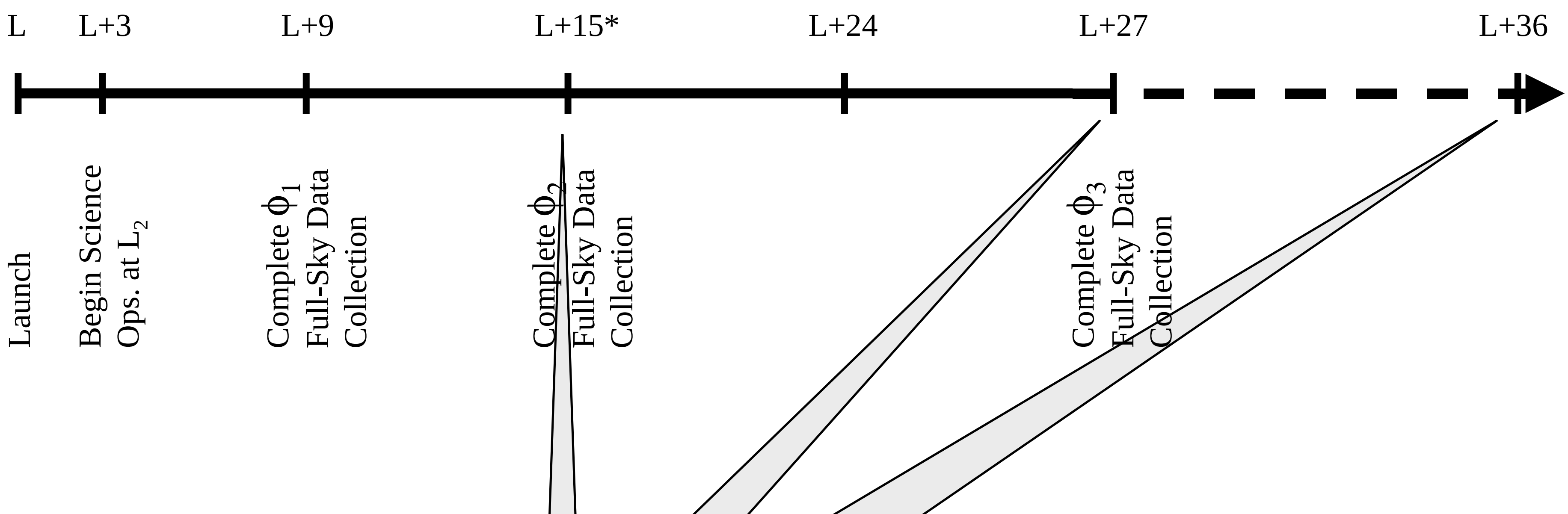
2) Check all signals for limit violations.

3) Update points in a trend archive for long-term instrument monitoring.

This software will operate in a similar fashion for I&T and in-flight.

MAP Data Timeline

Flight Operations Review



For each phase of data collection, ϕ_i:

- Complete new full-sky map solution by simultaneously fitting many billion (!) temperature differences
- Complete analysis of instrument calibration and uncertainties
- Set upper limits on residual systematic contamination in the sky maps
- Deliver calibrated temperature anisotropy maps (1 from each of MAP’s 10 data channels) with quantified random and systematic uncertainties

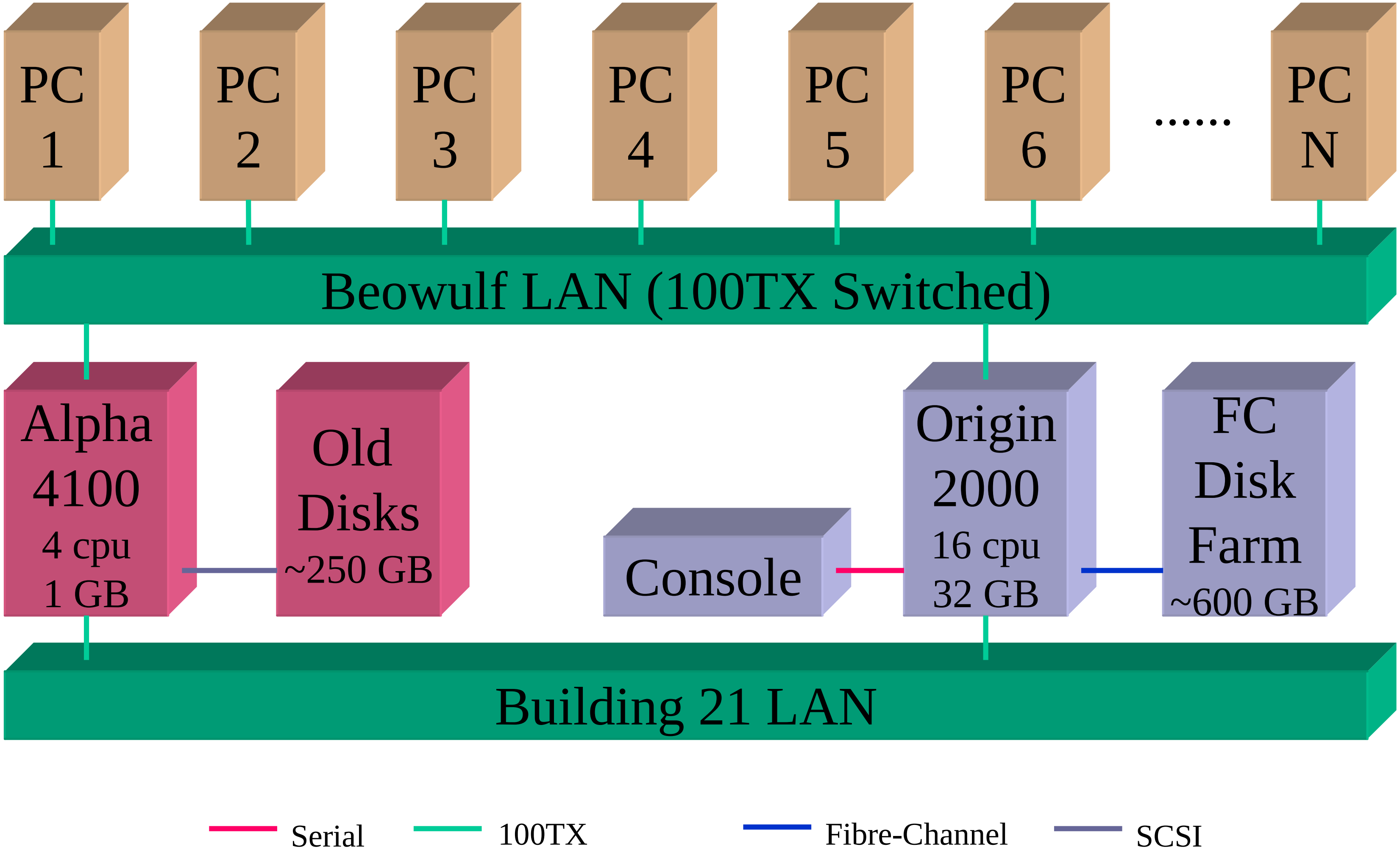
*Observations of the planet Jupiter are required in order to properly calibrate the instrument beam response. Because Jupiter is only visible during certain times of the year, this requirement could cause the completion of the first full-sky maps to be delayed by up to 3 months, depending on launch date.

Risks

- Any increase in mission operations costs beyond the MAP project's control could risk data analysis efforts under a tight and fixed MO&DA budget.

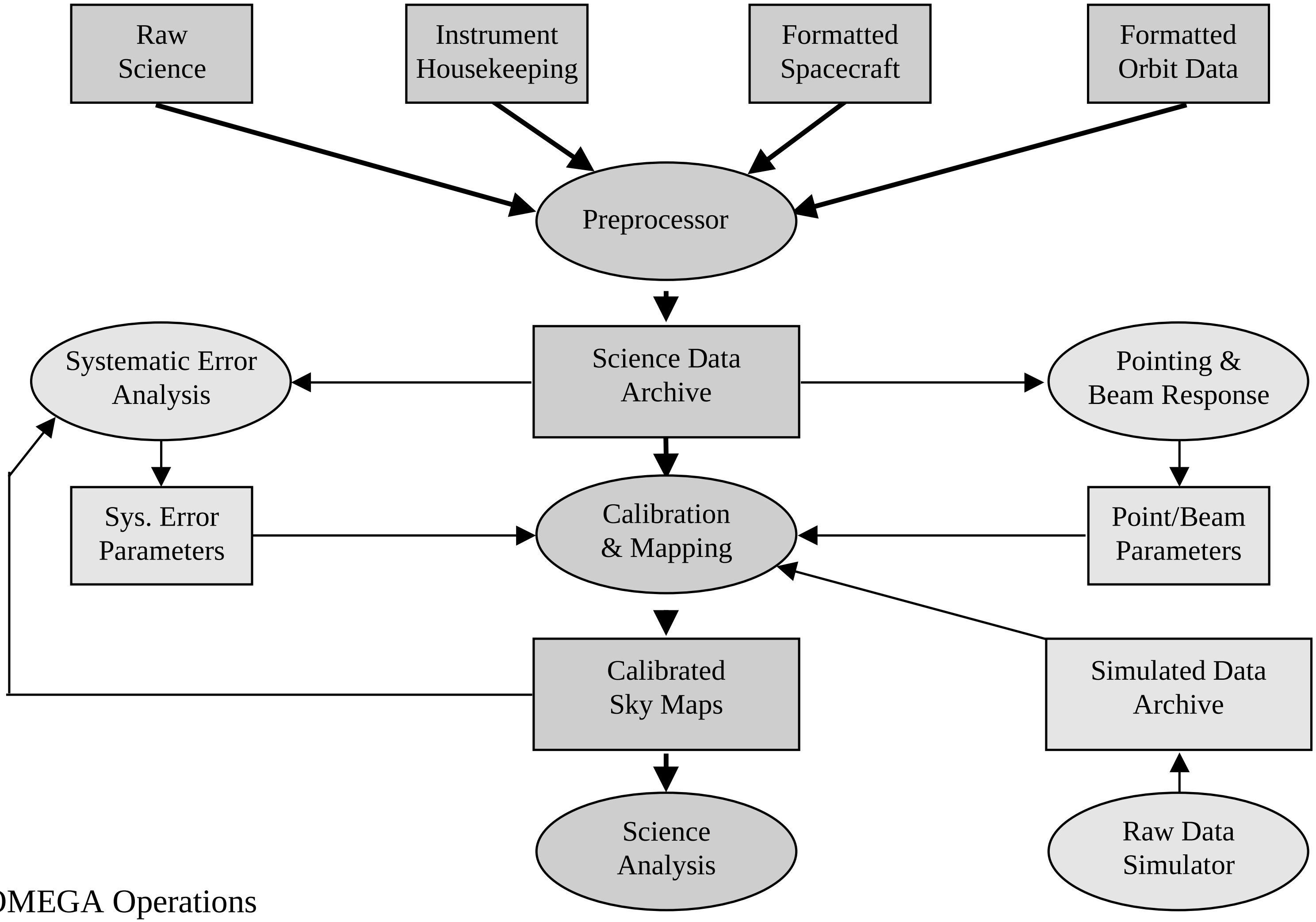
Backup slides

OMEGA- Server Architecture



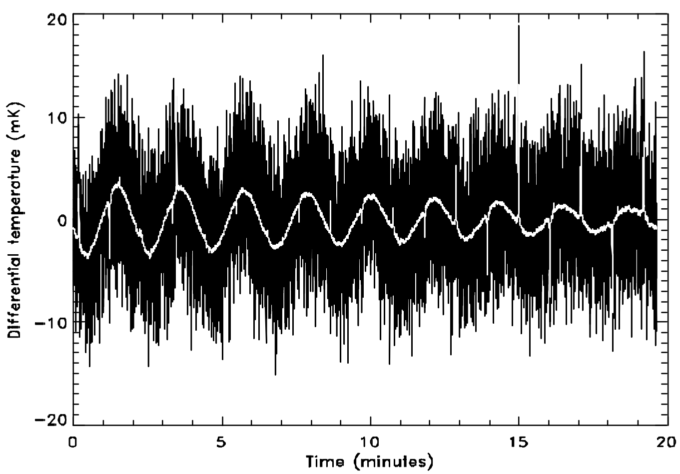
Science Data Pipeline

Flight Operations Review



Simulator Status

- Code to generate raw differential science data from input sky maps and scan data.
  - 90% complete.
  - Need to add additional systematic error modules for future end-end testing, including:
    - far sidelobe pick-up
    - “generic” spin-modulated signals (recently completed)



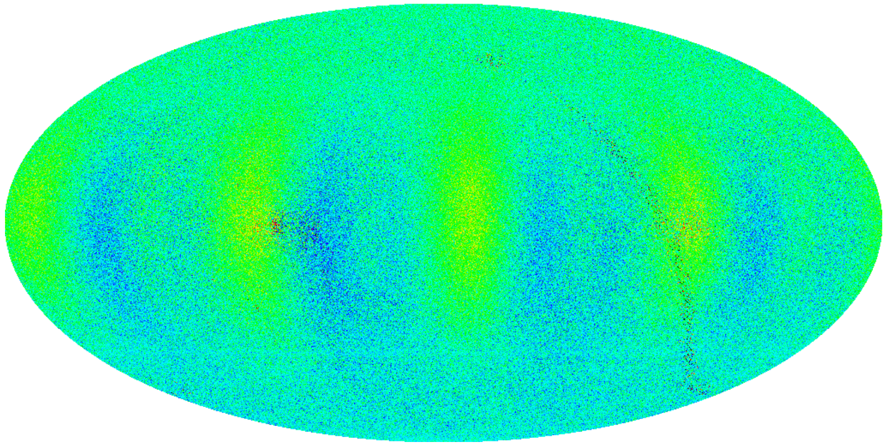
The figure at left shows a sample of calibrated differential data produced by the simulator. Features include a large modulated signal due to the CMB dipole (in white) and nominal Q band instrument noise superposed in black.

Preprocessor Status

- Code to merge Level 0 files from ground system into master science archive.
  - 95% complete.
  - Need to implement final format of attitude and spacecraft packets.

Calibration and Map Making Status

- Code to generate calibrated sky maps from the raw differential data.
  - 85% complete, including 10 channel processing with polarization.
  - Need to integrate “earth velocity” dipole effects into the calibration code.
  - Need to merge calibration code with new MPI parallel implementation of the map-making code.
  - Need to drop in systematic error correction modules as necessary.



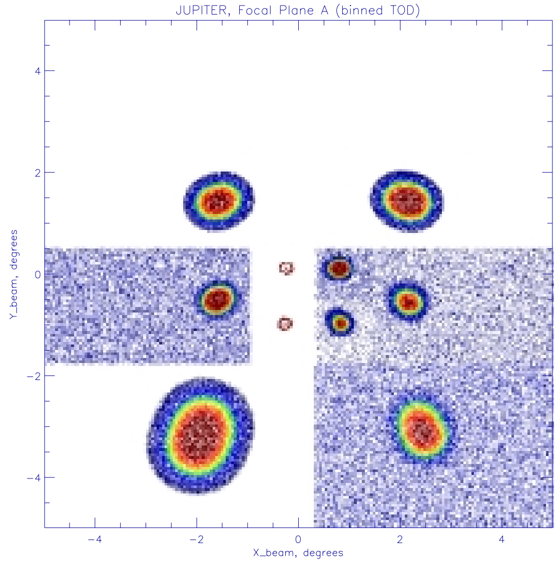
The sky map at left is a residual sky map (output - input) showing how well we recover the “true” sky (input) after running the map making algorithm for 20 iterations.

The color scale shown is ± 2 μK, and all remaining features in this map are understood to better than 1 μK.

Beam Mapping Status

Flight Operations Review

- Code to generate beam response maps from in-flight observations of Jupiter, Saturn, Mars.
  - 95% complete.
  - Need to clarify methods used to determine window functions from the beam maps - feeds into analysis of sky maps.



Sample focal plane map obtained from a simulation that includes scan smearing plus a model of intrinsic beam asymmetry. Some channels have nominal instrument noise, some have no noise.

* 1 σ noise level in a single nominal W band beam map: ~350 μK (10 arcmin pixel)
*Beam peak amplitude: ~250 mK
* Noise floor: ~ -28 dB (10 arcmin pixel)

Systematic Error Analysis Status

Routine description	Category	Status
Clean maps of far sidelobe contamination	Correction	15%
Correct for thermal/voltage susceptibility	Correction	10%
Bin science/housekeeping data by s/c configuration (eg. spin angle, precession angle)	Search/verify	80%
Bin science/housekeeping data by time (eg. transmitter on/off, solar activity)	Search/verify	0%
Differential response maps binned by source position in s/c coordinates (Sun, Earth, Moon, Planets, Galaxy)	Search/verify	85%
Power spectrum of instrument noise after correction for sky signal estimate	Search/verify	50%
Trending of all science/housekeeping signals	Verify	80%

Sky Map Analysis Status

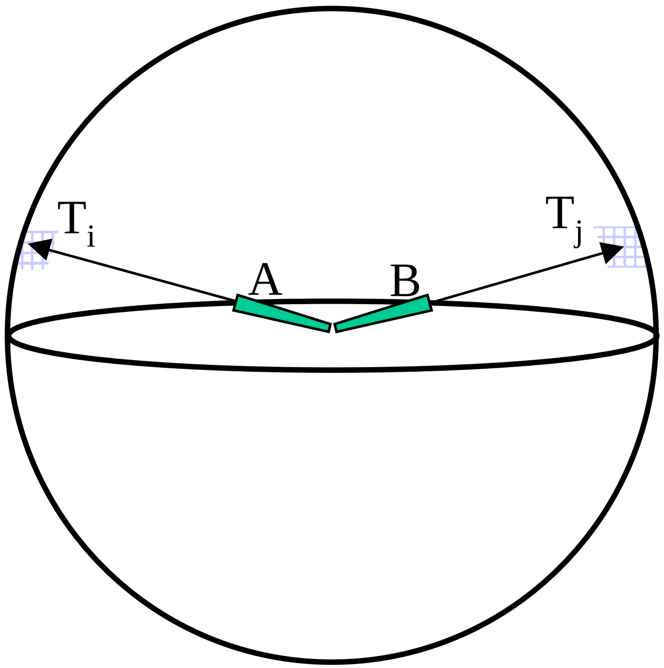
- Code to compute angular power spectra from calibrated sky maps.
  - 60% complete.
  - Code to analyze a single frequency map exists and demonstrates major elements of the algorithm.
  - Code for simultaneously analyzing multi-frequency maps is a straightforward extension of the above and is in development.
  - Code for analyzing power spectrum of the polarization has only been outlined.

Mapping with Differential Data

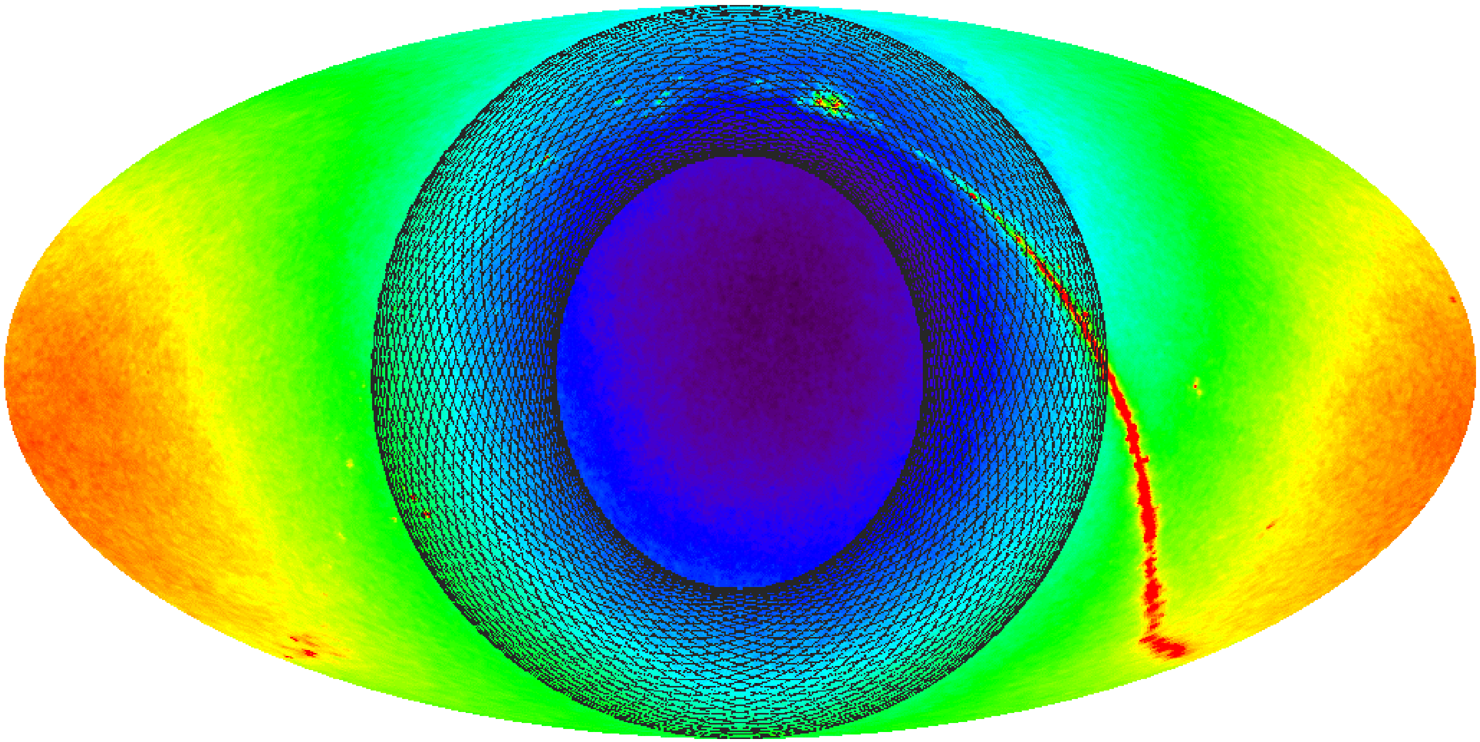
- The problem:
  - To produce a temperature map with 1-2 million pixels from a few billion temperature difference observations.
- The solution:
  - An iterative implementation of the least-squares fit used by COBE.
  - Wright, Hinshaw, & Bennett, Astrophysical Journal, 1996.
- The scheme:

$$\Delta T = T_i - T_j$$

$$T_i^{(n+1)} = \Delta T + T_j^{(n)}$$

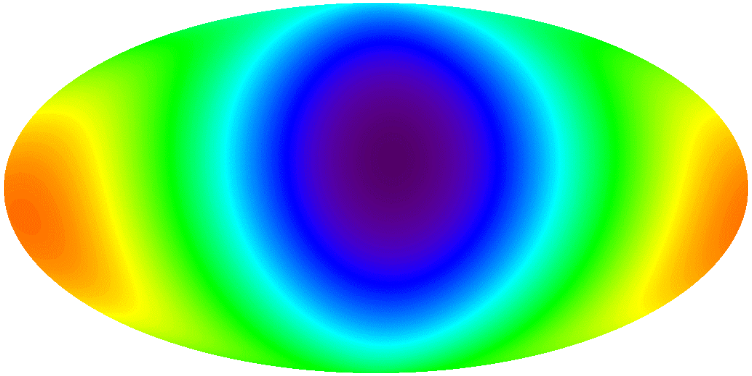


Model Sky Map with 1-hour Scan

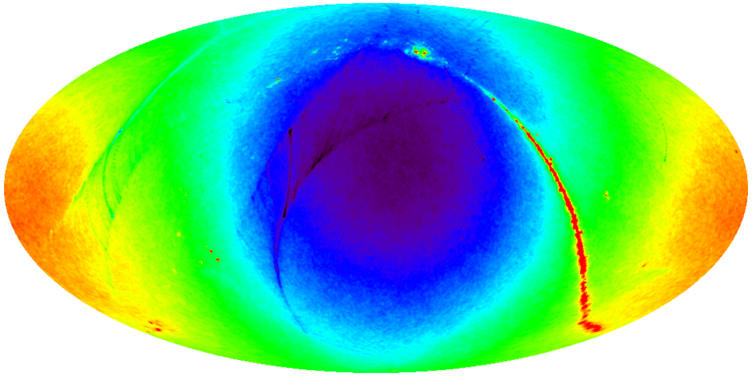


A and B lines-of-sight superposed on model sky map; one hour coverage, ecliptic coordinates

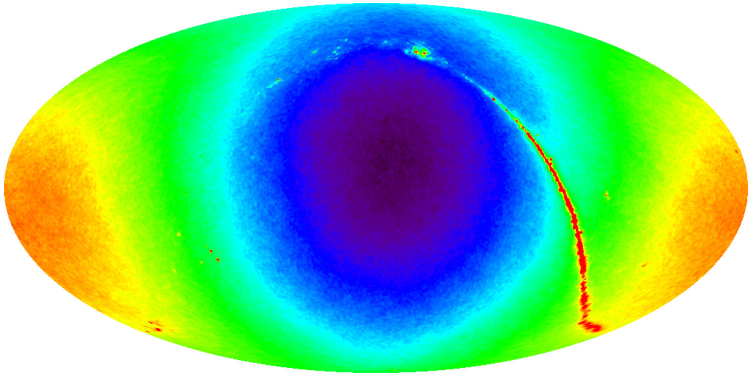
Map-making Illustration



Initial guess of sky temperature:
$I^{(0)}$ = pure dipole

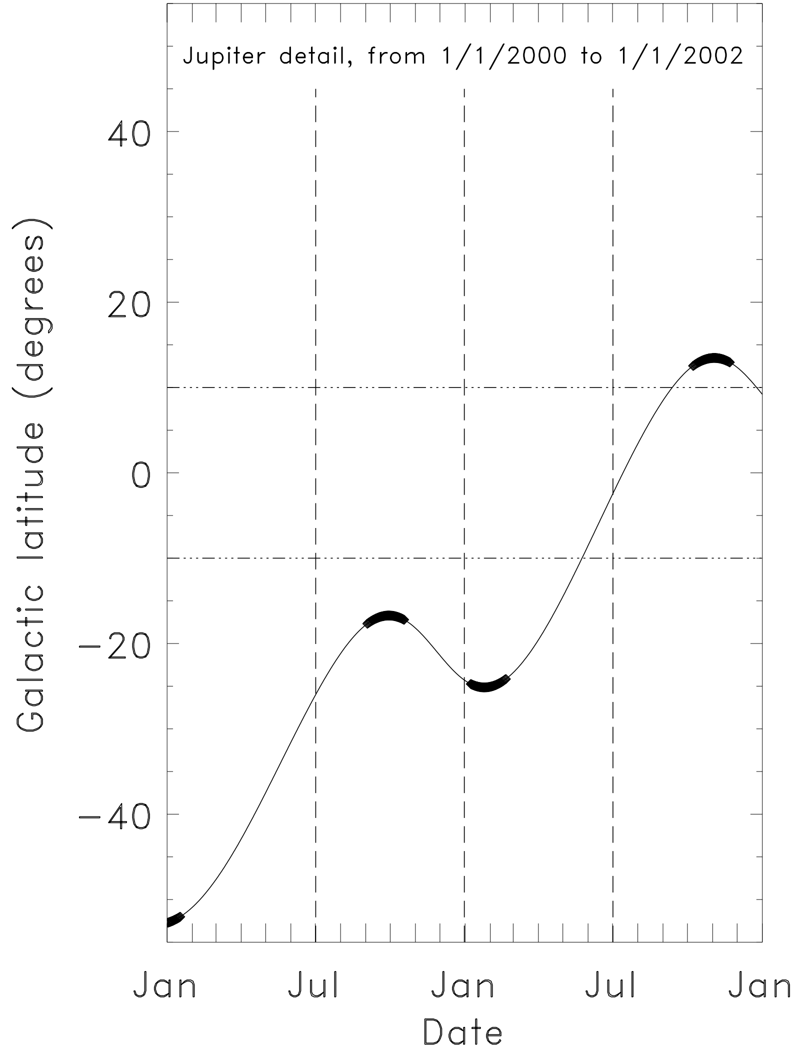


Response after 1 iteration -
note spurious "Galaxy echos"



Response after 10 iterations -
excellent convergence

Jupiter Ephemeris - Detail



Bold indicates times when Jupiter is visible to MAP for beam mapping.

Trajectory Design
&
Maneuver Operations

<u>GSFC:</u>

Osvaldo O. Cuevas

Michael Mesarch

Lauri Newman

Stephen Andrews

Gary Davis

<u>AI Solutions:</u>

Conrad Schiff

Dave Rohrbaugh

Becky Mesarch

Daryl Carrington

<u>AGI / SEE:</u>

John Carrico

Brent Helleckson

Mike Loucks

April 5, 2000

AGENDA

- Update from December Peer Review
- Trajectory Requirements Overview
- Baseline Trajectory
- Launch Window
- Maneuver Operations
- Orbit Determination Error Analysis
- Contingency Studies
- Operations Staffing
- Schedule
- Issues

Update from December Peer Review

Status Since December 99 Trajectory Peer Review

- Trajectory Peer Review held on Dec 15, 1999
- A total of 24 actions items were written by the review panel
- Contractor support for trajectory design was changed
- Tiger Team was formed to address Action Items from the peer review
  - **Charter:** identify work needed to be done in the trajectory and maneuver operations area to achieve a successful mission.
  - The team has representatives from all areas of the MAP support
- A Maneuver Team was established to coordinate maneuver planning, simulation and execution procedures (includes reps from Trajectory Design, ACS, Propulsion, Flight Software, S/C Controller, Navigation)
- A response to all 24 actions items was provided to the review panel (Report has been delivered).
- Tiger Team is now the Operations Working Group
  - Meets once a week and monthly status reviews have been held to monitor progress. These monthly meetings have been supported by members of GNCC and several members of the peer review panel

Status of Action Items (1 of 6)

- **A.I #1 Requirements must be clearly defined an understood by all the subgroups in the MAP projects. The entire team should be empowered to highlight any issues to the Project management;communications is critical**
  - Several Configuration Change Requests (CCR's) have been submitted to the CCB to clarify some of the requirements.
  - The implementation of the Operations Working group and monthly status reviews have improved communications within the different subgroups in MAP.
- **A.I #2 Review all requirements that constraint the launch period**
  - All requirements have been reviewed by the tiger team. Several CCRs were written and approved by the project
- **A.I #3 For each launch window that is identified, define nominal trajectories and a nominal open lissajous.**
  - A nominal trajectory has been defined for each launch day given an instantaneous launch window.
  - Work is in progress to widen the launch window each day to a maximum of 20 minutes. Once this work has been completed, a new nominal trajectory will be chosen for the new window.
- **A.I #4 Deterministic and random errors must be clearly distinguished from one another**
  - The trajectory team has worked with the other subsystems to quantify the errors.
  - After completion of AI#3 and OD error analysis, a systematic error analysis will be performed on all nominal trajectories

Status of Action Items (2 of 6)

Flight Operations Review

- **A.I #5 Systematic error analysis must be performed for each nominal trajectory to determine the impact of errors on the fuel budget and the ability to satisfy the constraints.**
  - Maneuver planning and recovery error analysis is underway. It will be followed by an OD error analysis which will determine whether maneuver errors result in a violation of the mission constraints. When complete, the trajectory team will determine an approach to satisfy all mission constraints within the fuel budget.
- **A.I #6 Identify a list of maneuver failures what most critically affect the mission and develop contingency plans to cope with this failures.**
  - Worked with the ACS and propulsion subsystem leads; identified 5 potential maneuver failure scenarios.
  - Scenarios were prioritized, and plans to overcome the failures will be developed using the Nov 8 baseline trajectory.
- **A.I #7 There were three teams working independently which overlapped heavily. It is recommended that this strategy be reevaluated**
  - The team has been refocused into one united group for all current and future efforts.
  - Due to the criticality of the DTO delivery, a second team was retained through that time to ensure a successful delivery.
- **A.I #8 Further investigation of the perigee constraint and/or additional maneuvers to meet requirements is warranted if it is viable within the existing fuel budget.**
  - A CCR was written to lower the minimum perigee altitude from 1000 km to 500 km.
  - The requirement to avoid A1 maneuvers was lifted. It is still desired to avoid them when possible.

Status of Action Items (3 of 6)

- **A.I #9 Burn model simulation and truth model is not clear. Clarify how a maneuver is going to be planned, performed and confirmed. Do not perform momentum dumps in the final perigee.**
  - A maneuver plan and execution flow diagram is being drafted.
- **A.I #10 Determine whether the burn models have the fidelity to accurately determine the spacecraft orbit and attitude. In particular, make sure they include "small forces" like momentum dumps.**
  - HiFi and FlatSat include force and torque for each thruster as well as plume impingement torques.
  - All subgroups have the same modeling in their software and values are controlled by a shared database.
  - Working to quantify affect of ~1 sec Delta H on maneuvers - may consider implementing a Delta H "blackout" period prior to stationkeeping maneuvers if necessary.
- **A.I #11Modify Astrogator to plan and calibrate maneuvers using the command quaternion table from the spacecraft, and to read an electronic state vector from the OD process. Verify coordination between maneuver planning and mission design teams using end-to-end testing.**
  - Astrogator will be able to ingest the CQT and read a vector from the OD software.
  - The MAP Maneuver Planning Team includes both the mission design and maneuver planning people. The detailed interactions are being documented and will be tested during simulations.

Status of Action Items (4 of 6)

- **A.I #12 The maneuver team should be ready to react rapidly in the case of missed burns or burns out of specification.**
  – It is part of the maneuver team plan, to have contingency maneuvers ready to go and have a quick turnaround process ready for implementation.
- **A.I #13 Telemetry and command must be available during the burns in the phasing loops.**
  – The agreement between RFICD and the MAP spacecraft have been modified to reflect the new requirement for a TDRS forward link service to ensure telemetry and command during all perigee maneuvers.
- **A.I #14 Momentum dumps should not be performed when performing an Orbit Determination.**
  – No momentum unloads will be planned at least 24 hours prior to maneuvers.
- **A.I #15 The "worst case" design philosophy might be too conservative. Investigate multi-dimensional statistics and specify Delta -V budget according to a given probability level**
  – The propulsion budget has been thoroughly reviewed as part of the trajectory design and maneuver planning effort. Although we have adopted a conservative approach, the budget supports all of MAP requirements and allows an adequate monthly and daily launch window.

Status of Action Items (5 of 6)

- **A.I #16 ACS and Navigation team need to define the interfaces between them for both pre and post-maneuver information.**
  - Interfaces between both teams are being worked out. Interface will be documented through memo of understanding.
- **A.I #17 When the ACS and the other teams interfaces are defined, an end-to-end of the data should be performed as soon as possible.**
  - Interfaces are being worked out. Through simulations we will test each one of these interfaces. The first maneuver included and end to end flow, with some of the interfaces simulated.
- **A.I #18 STK/Astrogator software should be enhanced to read a CQT file, or an equivalent file for accurate maneuver reconstruction.**
  - AGI will deliver this enhancement in an Astrogator release currently scheduled for the end of April.
- **A.I #19 If it is necessary to transform between quaternions and angles, then the conversion should be tested extensively to make sure there are no singularities.**
  - Everything is done with Quaternions so no conversion is necessary. CQT has been tested and verified as part of the ACS flight software build and acceptance testing.
- **A.I #20 The Navigation team must use the most accurate values available for duty cycle and thrust scale factor for each thruster.**
  - This is being worked as part of the memorandum of understanding between the trajectory and ACS teams.

Status of Action Items (6 of 6)

- **A.I #21 If it is practical to compute thruster misalignments along with thrust scale factor, then the interface of ACS and the maneuver team must include the misalignments. The Nav and ACS teams s/w should be designed to accept thrust misalignments and these mods should be tested.**
  - The ACS FSW has the ability to accept thruster misalignments, and this capability has been used to introduce uncertainties in the modeling of maneuvers.
- **A.I #22 It appears that not all tools and software have been flight qualified. Formally document all tools that will be used and the formal verification plan(schedule and checklist).**
  - All tools/software planned to be used in MAP operations have or will have undergone separate validation programs.
- **A.I #23 Contingency planning is behind schedule.**
  - Contingencies have been identified and prioritized.
  - Work has started on the contingencies identified.
- **A.I #24 Whenever possible utilize information from previous missions but do not rely solely on it. All areas should be properly verified and analyzed.**
  - Members of the trajectory team have supported similar missions (I.e, ACE, SOHO, WIND) and Clementine. Whenever possible we will use information and expertise gained from previous missions.
  - All areas will be properly verified and analyzed through Simulations

Trajectory Requirements Overview

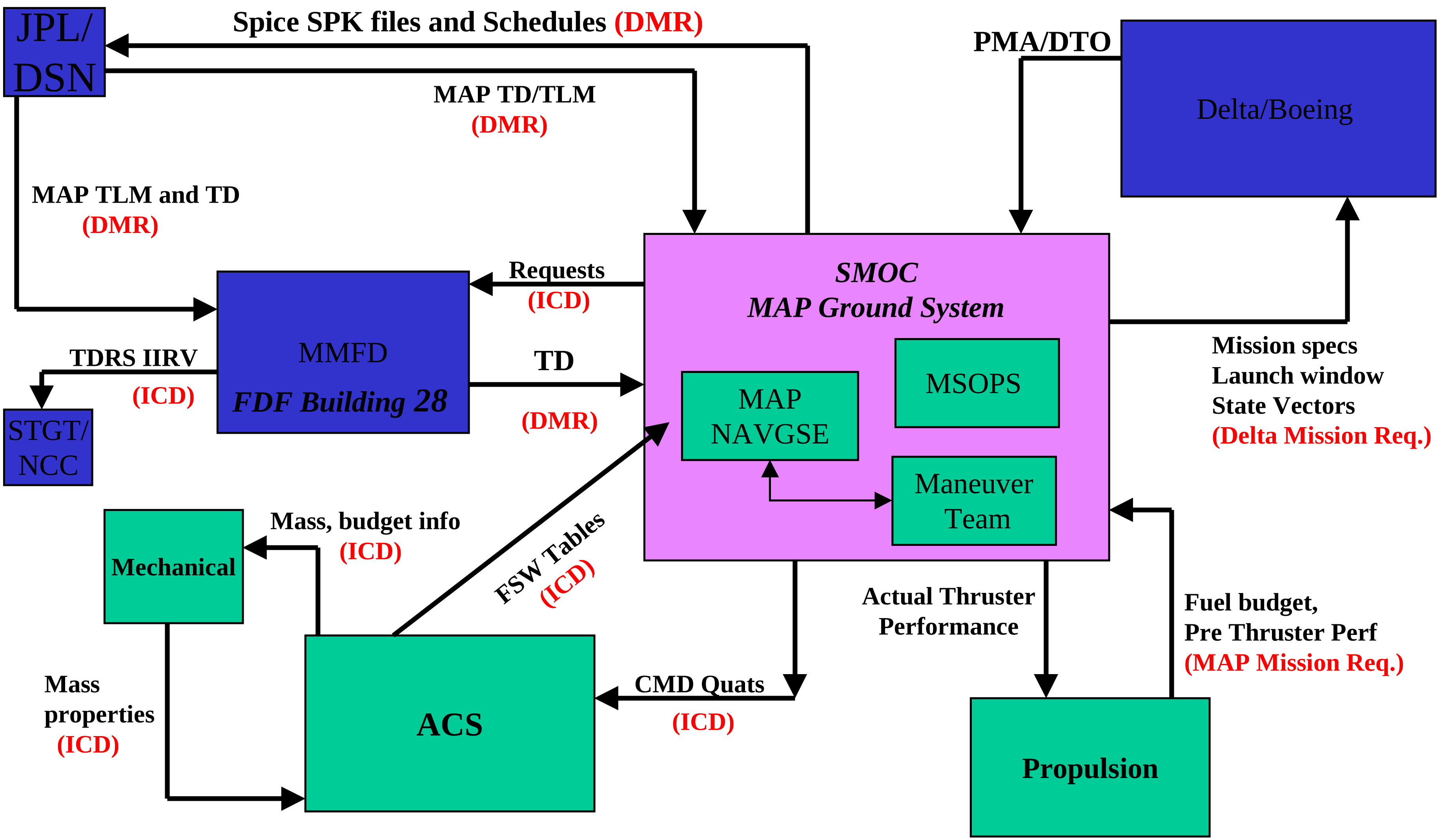
MAP Trajectory Requirements

#	Title	SMRD Functional Requirement	SMRD Performance Requirements	Trajectory Dervied Requirements
2.2.1			The mission life shall be 27 months.	
3.5	Orbit	Minimize the variability of the instrument's environment while it is observing.		
3.5.1			Assure an L2 Lissajous orbit with a minimum SEV angle to avoid all Earth shadows and with a maximum SEV angle of 10.5 degrees to assure sufficient RF communications gain from the fixed Medium Gain Antennas.	
3.5.2			The observatory shall not encounter earth or lunar shadows after the thermal constraint transition point (defined in Requirement 6.4.7).	
3.5.3			Observatory shadowing is allowed prior to the thermal constraint transition (defined in Requirement 6.4.7) as long as the battery depth of discharge does not exceed 40%.	
5.5	Trajectory	The launch vehicle shall deliver the observatory to a transfer trajectory from which an observatory supplied propulsion system shall deliver the observatory to L2.		
5.5.1			The launch vehicle shall provide a 831 kg throw weight to a 28.7 deg (ETR) inclination orbit with a C3 of -2.6.	3rd stage burn start no earlier than L+20 min or later than L+120 min
5.5.2			The minimum perigee for any trajectory shall be no lower than 500 km.	
5.5.3			Launch vehicle errors shall be no greater than +-11.6m /s (3 sigma) in magnitude and +-2 deg (3 sigma) in pointing.	
6.4	Delta-V Maneuvers	Provide the capability for trajectory correction and orbit maintenance.		
6.4.1			At L2, Delta-V maneuvers shall be in concert with momentum maneuvers.	
6.4.2			A non-spinning three-axis control mode shall be used for orbit maneuvers.	
6.4.3			Pointing control for all delta-V maneuvers shall be +/- 5 degrees per axis, 3 sigma.	
6.4.4			The spacecraft shall provide the capability for the ground to uplink an attitude profile to be used in conjunction with Delta V maneuvers	
6.4.4.1			It is the responsibility of the ground to ensure the attitude profile uplinked with the capability described above meets the constraints described below	
6.4.5			During orbit adjust maneuvers up to and including the thermal constraint transition, the commanded spacecraft orieintation shall maintain the spacecraft +Z axis within +/- 55 degrees of the sunline in the spacecraft's XZ plane and within +/- 25 degrees of	
6.4.6			During orbit adjust maneuvers after the thermal constraint transition, the commanded observatory spin axis shall be 20 degrees to the sun +/- .1 degrees.	
6.4.7			The thermal constraint transition shall occur two weeks after lunar swingby.	

MAP Trajectory Requirements

6.5	Delta-V Maneuver Predictability	The execution of delta-V maneuvers shall be sufficiently predictable to achieve the required mission trajectory within the propellant allotment.		
6.5.1			The uncertainty in delta-V due to thruster force variations shall be <= 5%.	
6.5.2			The observatory attitude control shall provide the commanded delta-V to within 1%, inclusive of pointing errors and quantization.	
6.5.3			Uncertainty due to ground system modeling errors shall be limited to 1%.	
6.6	Delta-V Budget	Provide sufficient Delta-V budget for the life of the mission.		
6.6.1			Delta-V of 10 m/s shall be provided for thruster calibration.	
6.6.2			Delta-V of 10 m/s shall be provided to accommodate a daily 20-minute launch window.	
6.6.3			Delta-V of 60 m/s shall be provided for trajectory maneuvers.	A total of 70 m/s is available for an instantaneous launch window. The largest Pf shall be less than 30 m/s. Minimize Pf by using P1 and P2 where possible.
6.6.4			Delta-V of 15 m/s shall be provided for final perigee maneuver correction.	
6.6.5			Delta-V of 10 m/s shall be provided for a mid-course correction maneuver.	
6.6.6			Delta-V of 4 m/s shall be provided for stationkeeping for each year of observing at L2.	
6.7	Momentum Management	Provide for necessary momentum maintenance.		
6.7.1			The system shall be able to unload momentum down to .3 N-m-s, and shall not allow instrument exposure to the sun.	
6.7.2			The capability to unload momentum for the life of the mission shall be provided.	
6.7.3			At L2, momentum maneuvers shall be limited to <= 4 per year, and shall not interrupt the observing mode for more than 2 hours.	
6.7.4			The observatory shall remove angular residual launch vehicle momentum.	
6.7.5			During momentum maneuvers after the thermal constraint transition (defined in requirement 6.4.7), the commanded observatory spin axis shall be 20 degrees to the sun +/- .1	
6.7.6			Pointing control for all momentum maneuvers shall be +/- 5 degrees per axis, 3 sigma.	
11.4	Tracking	Sufficient tracking capabilities shall be provided for the mission.		
11.4.1			Definitive orbit determination accuracy of <=10 km shall be supported for orbit maintenance at L2.	CCR pending
11.4.2			Definitive orbit determination accuracy of <= TBS m shall be supported for phasing loops and lunar assist planning.	CCR pending
11.4.3			Velocity determination of 2 cm/sec accuracy shall be supported at L2.	CCR pending
11.4.4			Velocity determination of TBS cm/sec accuracy shall be supported during the phasing loops.	CCR pending
13.9	Orbit Products	Orbit products sufficient for science and mission planning shall be provided.		

Standard Navigation Subsystem Data Flow/Interfaces



( ) represents documents or interfaces

Documentation Status

- PMA and DTO memos for Nov and Dec launch dates have been completed
- Detailed Mission Requirements (DMR) signed
- ICD between MMFD and NCC done
- ICD between MAP Navgse and MMFD in place
- Memo of Understanding between ACS and Maneuver team (in progress)
- Memo of Understanding between Maneuver team and Propulsion (in progress)
- Memo of Understanding between Navgse and Maneuver team (in progress)
- Memo of Understanding between ACS and Navgse (in progress)
- Memo of Understanding between Mechanical and ACS (in progress)

Note: All the documentation will be under Configuration Control

Baseline Trajectory

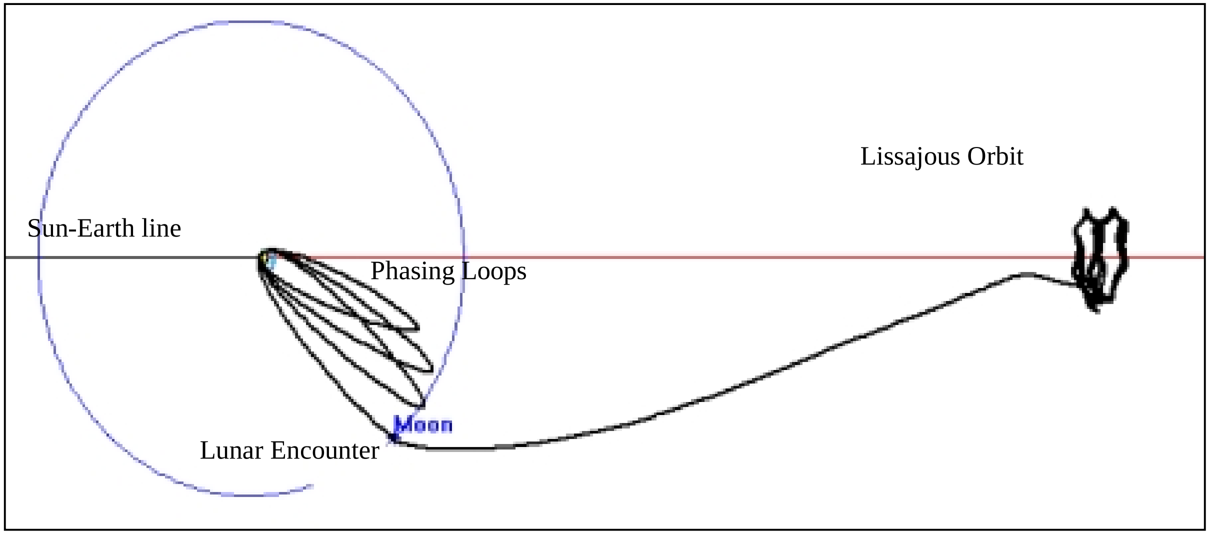
MAP Orbit Maneuvers

- MAP utilizes a phasing loop (3 or 5) / lunar swingby strategy to achieve its L2 mission orbit
- The maneuvers listed to the right are required to meet this goal

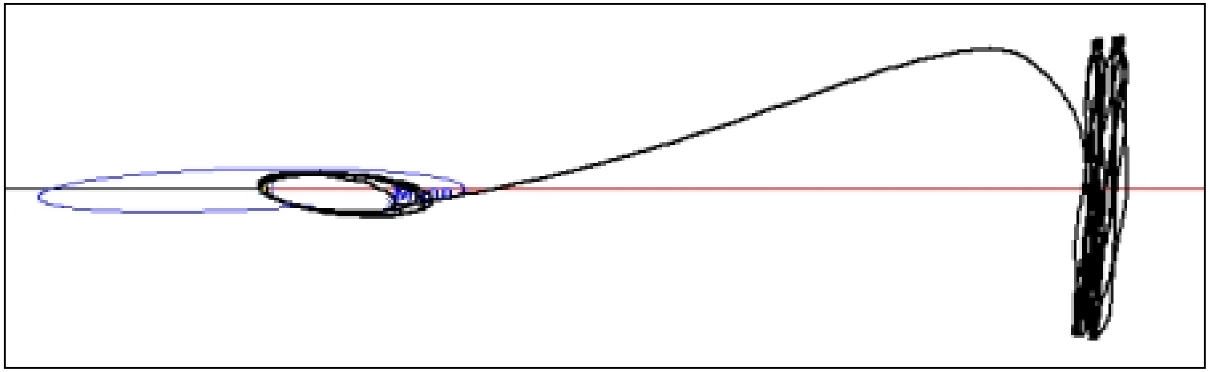
- Calibration Maneuvers
  - Characterize thruster sets
- Phasing Loop Apogee Maneuvers
  - used to maintain minimum perigee height of 500 km
  - inertially fixed orientation
- Phasing Loop Perigee Maneuvers
  - soak-up launch vehicle errors
  - used to control the Lunar Swingby energy and orientation
  - s/c attitude follows velocity vector during maneuver
- Pf Correction Maneuver
  - correction maneuver after final perigee maneuver
- Mid-Course Correction
  - correction maneuver after lunar swingby
- L2 Stationkeeping Maneuvers
  - used to maintain orbit about L2
  - maneuver planned every 3 months
  - s/c maintains 20° sun-line angle
- L2 Lunar Shadow Avoidance

The MAP Trajectory

Sun-Earth-Moon Rotating Libration Point Coordinate System



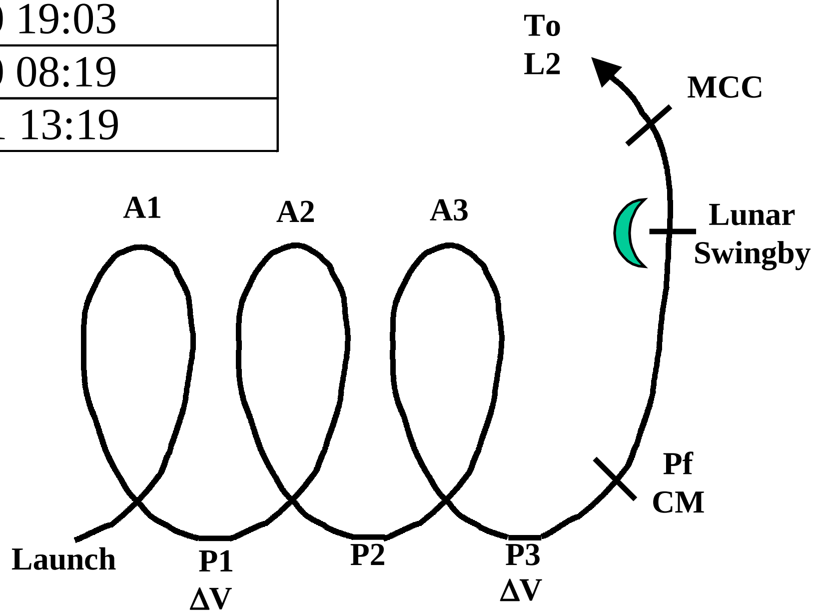
top view



side view

MAP Timeline (11/07/2000 Launch)

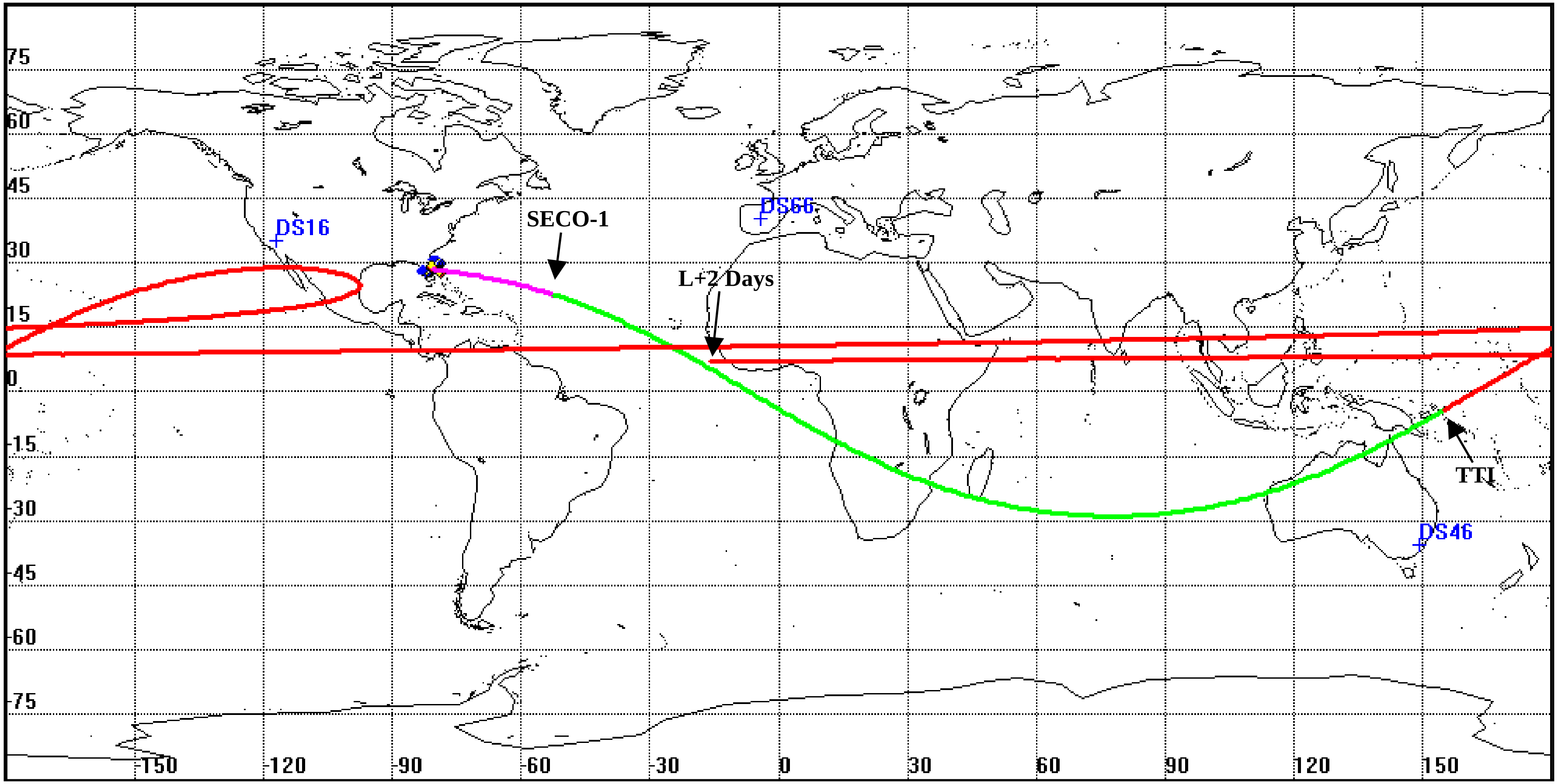
Event	Date (UTC)
Launch	07 Nov 2000 23:10 (est.)
A1	11 Nov 2000 13:29
P1	15 Nov 2000 01:43
A2	19 Nov 2000 18:23
P2	24 Nov 2000 11:13
A2	29 Nov 2000 03:01
P3	03 Dec 2000 19:03
Lunar Swingby	07 Dec 2000 08:19
L2 Insertion	10 Mar 2001 13:19



MAP Early Mission Groundtrack

Flight Operations Review

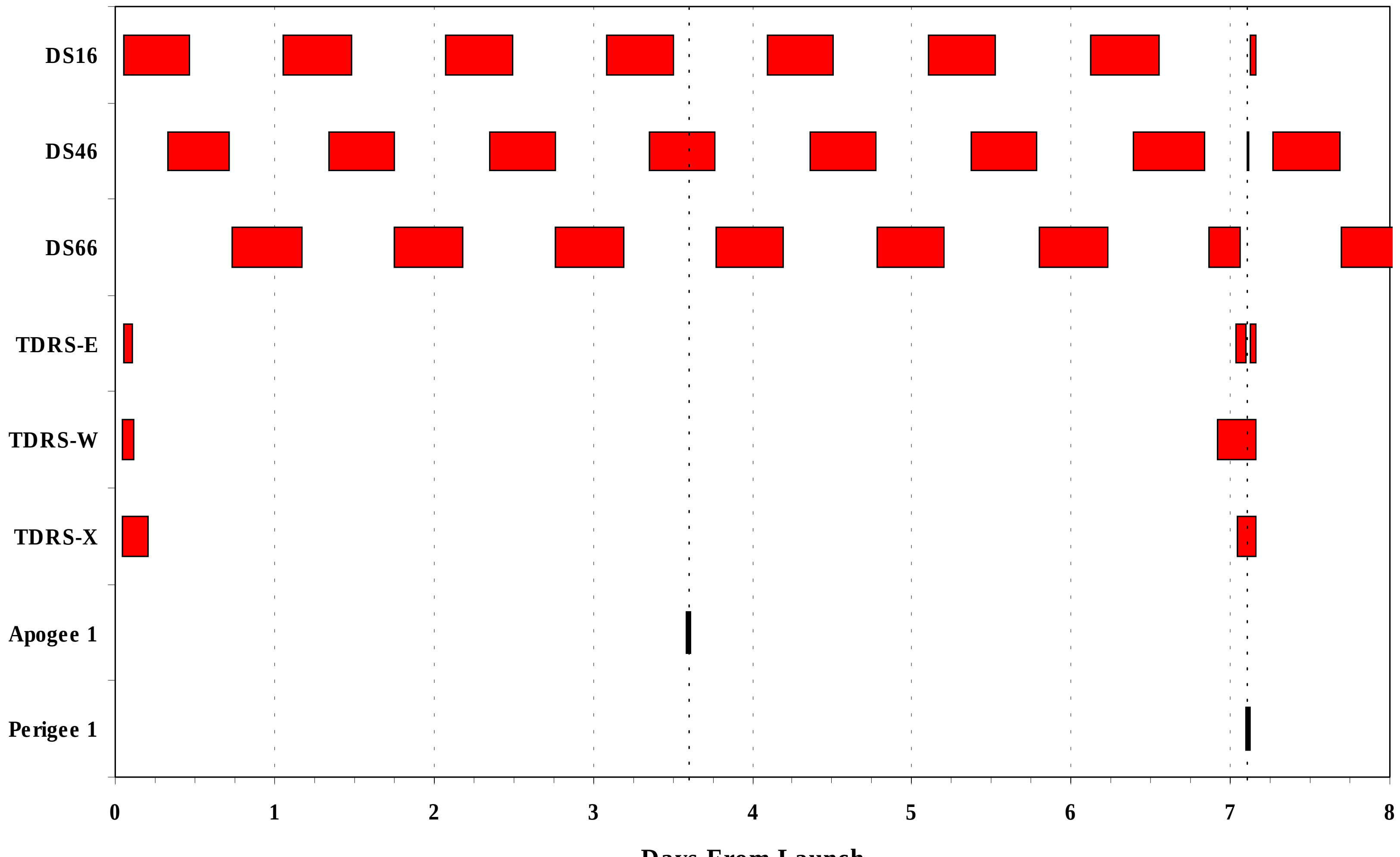
November 7, 2000 Launch



MAP Early Orbit Station Visibility-Through First Perigee

Flight Operations Review

November 7, 2000 Launch



MAP ΔV Budget

- Based on the requirements, the MAP ΔV Budget is

Maneuver	ΔV (m/s)
ELV Tip-off	0
Calibration	10
Phasing Loop Maneuvers (Including ELV Dispersions)	60
Daily Launch Window	10
Pf Correction	15
Post-Swingby MCC	10
L2 Stationkeeping (2 Years)	8
L2 Lunar Shadow Avoidance	20
Total	133
Margin*	18

Limit

* Potential liens against margin include: Phasing loop shadow avoidance & contingencies

Delta-V Allocation for 11/07/2000 Launch

Flight Operations Review

- An example Delta-V budget is shown for the November 7th Launch opportunity - instantaneous launch opportunity
- As per budget requirements, the shaded Delta-V sum must be:
  - < 60 m/s for instantaneous launch window
  - +10 m/s for finite launch window

November 7th Launch

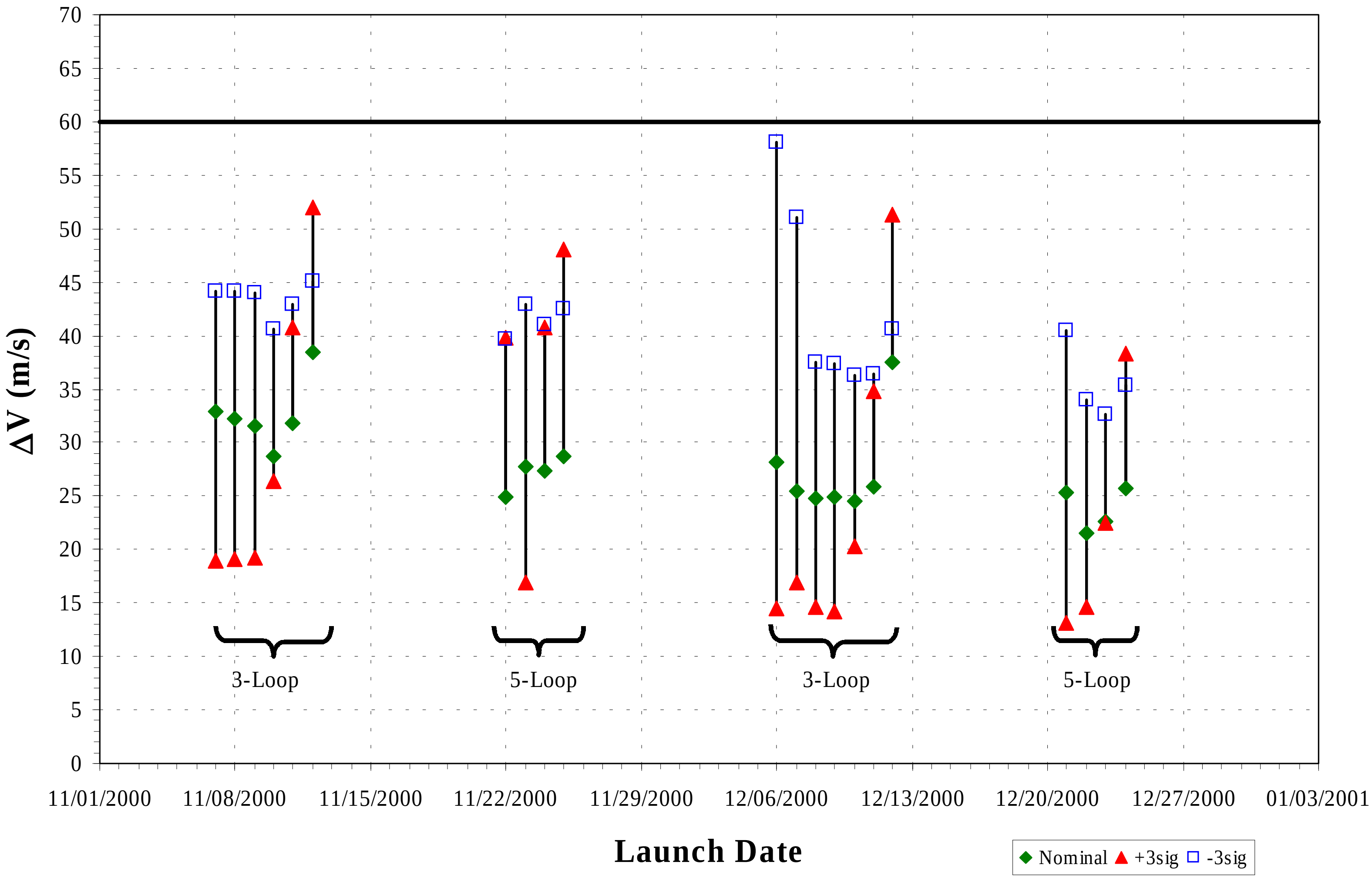
Maneuver	Nominal Impulsive Δv (m/s)	$+3\sigma$ Impulsive Δv (m/s)	-3σ Impulsive Δv (m/s)	Description
+X Cal				+X Calibration Maneuver (Thrusters 5, 6, 7, & 8)
-Z Cal	←	10.000	→	-Z Calibration Maneuver (Thrusters 1 & 2)
+Z Cal				+Z Calibration Maneuver (Thrusters 3 & 4)
A1	0.000	0.000	0.000	Apogee 1 Maneuver
P1	24.463	3.155	39.000	Perigee 1 Maneuver
A2	0.000	0.000	0.000	Apogee 2 Maneuver
P2	0.000	0.000	3.603	Perigee 2 Maneuver
A3	0.000	0.000	0.000	Apogee 3 Maneuver
P3	8.504	15.818	1.582	Perigee 3 Maneuver
A4	NA	NA	NA	Apogee 4 Maneuver
P4	NA	NA	NA	Perigee 4 Maneuver
A5	NA	NA	NA	Apogee 5 Maneuver
P5	NA	NA	NA	Perigee 5 Maneuver
PfCM	15.000	15.000	15.000	Correction Maneuver after Final Perigee Maneuver
MCC	10.000	10.000	10.000	Correction Maneuver after Lunar Swingby
L2SA	20.000	20.000	20.000	L2 Shadow Avoidance
SK_1				Stakionkeeping Maneuver 1
*				"
*	←	4.000	→	"
*		(per year)		"
SK_N				Stakionkeeping Maneuver N

November 7 Constraints

Date	Nov 7		
Case	**nom**	**+3σ**	**-3σ**
Perigees > 500 km	yes	yes	yes
PL DV (m/s)	32.97	18.97	44.19
A1 Maneuver	No	No	no
Phasing Loop Lunar Shadows	no	no	no
Cruise Lunar Shadow	no	no	no
L2 Lunar Shadow	no	yes	yes (2)
max depth (%)	---	11.5	4.0| 2.9
duration (min)	---	225	360| 226
Halo Max (deg)	8.3	7.9	7.7
Halo Min (deg)	0.6	1.2	0.54

MAP Phasing Loop ΔV
(Instantaneous Launch)

Flight Operations Review



Propellant Budget Overview

- Requirements Flowdown
  - Mission requirements --> m/s --> kg of propellant
- Calibrations
- Propellant Gauging
- Assumptions used in budget calculations
- 3 Example Budgets
  - "Worst case 4 thrusters" budget which captures all requirements
  - "Worst case 2 thrusters" budget simulates using 2 thrusters for ΔV
  - "Reference case" budget uses the nominal 7 Nov 00 trajectory
- Overview of budgets for all existing trajectory cases
  - November and December; 3 and 5 loop; ±3 sigma launch vehicle
- Margin
- Summary

Requirements Flowdown

EVENT	MSMR Rev. 12	REQUIREMENT VALUE	CONVERSION TO PROPELLANT (831 kg S/C mass per MSMR 5.5.1)	"Worst Case 4 Thruster" BUDGET
TIP OFF	6.1.3	>2 sigma tip-off	Rates -> Inertias -> Momentum -> Torque -> Time calculation	0.1 kg
CALIBRATIONS	6.6.1	10 m/s	Duration -> Impulsive -> Blowdown Pressure -> Thrust -> Isp -> ACS calc.	4.6 kg
LAUNCH WINDOW	6.6.2	10 m/s	Impulsive to Finite Conversion -> Blowdown Pressure -> Thrust -> Isp -> ACS penalty calculation	33.3 kg
TRAJECTORY MANEUVERS	6.6.3	60 m/s		
Pfinal CORRECTION	6.6.4	15 m/s		6.8 kg
MCC	6.6.5	10 m/s	Impulsive -> Blowdown Pressure -> Thrust -> Isp -> ACS penalty calculation	5.0 kg
Shadow Avoidance	6.6.7 2.2.1	20 m/s 24 months		10.0 kg
Stationkeeping	6.6.6 2.2.1	4 m/s/year 24 months		4.00 kg
TOTALS	-	133 m/s + tip-off	-	63.8 kg
Unallocated Contingency	-	18 m/s	Propellant load – unusable propellant – required propellant calculation	7.6 kg

Calibration Maneuvers / 1

- Thruster verification performed using "one shots"
  - Each thruster fires one at a time for 1 sec duration, ~ 5 minutes apart
  - Repeat each thruster as soon as first series has been verified
  - Plume torque, misalignment, and thrust magnitude will be known from ACS and propulsion telemetry
- 6 Calibration maneuvers will be performed
  - Duty cycle characteristics / ACS mode behavior will be assessed
  - Thrust magnitude will be quantified from orbit determination
  - Minimum 6 hours apart; first set inertially fixed before apogee, second set with CQT after apogee

Calibration	Time	Direction	Attitude	Duration	Propellant	ΔV
"Cal. A"	Day 2 (before A1)	+X ΔV	inertial	1.7 min	0.90 kg	2.1 m/s
"Cal. B"	Day 3 (before A1)	-Z ΔV	inertial	1.8 min	0.47 kg	1.1 m/s
"Cal. C"	Day 3 (before A1)	+Z ΔV	inertial	2.2 min	0.49 kg	1.0 m/s
"Cal. D"	Day 4 (after A1)	+X ΔV	CQT	1.8 min	0.90 kg	2.1 m/s
"Cal. E"	Day 4 (after A1)	-Z ΔV	CQT	1.9 min	0.47 kg	1.1 m/s
"Cal. F"	Day 5 (after A1)	+Z ΔV	CQT	2.3 min	0.49 kg	1.0 m/s

- NOTE: Values in this table are for the expected 8.4 m/s of calibrations. 10 m/s are budgeted for calibrations

Calibration Maneuvers / 2

- "Thrust Scale Factor" will be configured in CM database
  - Used by Astrogator
  - Used by FlatSat
  - Used by HiFi
- Orient calibration maneuvers subject to:
    - maximum observability, minimum effect on orbit
    - subsystem constraints
- OD solution and spacecraft telemetry will be used in Astrogator to reconstruct the maneuver, and the Astrogator solution will provide a thrust scale factor that will be used in planning future maneuvers

Propellant Gauging

- Estimate propellant remaining after each maneuver
  - "PVT Method"
    - Uses tank pressure and temperature from telemetry
    - Calculates gas properties using ideal gas law
    - Determines ullage volume and remaining propellant volume
  - "Mdot Method"
    - Uses tank pressure, thruster valve on-time, analytical ΔP
    - Calculates mass flow rate from flight pressure and ground test data
    - Determines how much propellant has passed through each thruster
  - "Isp Method"
    - Uses tank pressure, valve on-time , analytical ΔP, thrust, and Isp
    - Calculates mass flow rate from thrust and Isp which are functions of P
    - Determines how much propellant has passed through each thruster
- An analytical model of tank pressure vs. total valve on-time is being developed in case transducer fails

Propellant Budget Assumptions

- Assumptions used in every budget:
  - 831 kg observatory mass
  - Initial propellant load of 72.57 kg
  - Initial tank pressure of 328 psia (assumes tank at 20 C, may reach 40 C)
  - 1.23 kg unusable propellant in tank and manifold
  - Cosine losses used for "+X" direction maneuvers of 7.5°
  - Cosine losses used for "+Z" direction maneuvers of 30°
  - ΔP calculated from orifice/pressure drop network analysis assumes 4 thrusters on
  - Isp calculated as a function of inlet pressure
  - 15 % ACS control propellant
  - 10 m/s of calibration maneuvers
  - 20 m/s of shadow avoidance maneuvers for 2 years at L2
  - 8 m/s of stationkeeping maneuvers for 2 years at L2
  - **Pfinal correction (15 m/s) and MCC (10 m/s) are included in every budget**
- 3 Budgets:
  - "Worst case 4 thrusters" assumes worst case trajectory & -3 sigma performance
  - "Worst case 2 thrusters" same as above with failed thruster (2 thruster delta-V)
  - "Reference case" uses nominal trajectory & nominal performance

“Worst case 4 thrusters”

- “Worst case 4 thrusters” is a worst-case trajectory
  - Uses all Delta-V required in the MSMR Rev. 12
- Key “Worst case 4 thrusters” assumptions:
  - “Worst case” finite burn penalties applied to phasing loop maneuvers as follows:
    - 40 m/s maneuver: 8 % finite penalty
    - 30 m/s Pfinal maneuver: 8 % finite penalty
    - 15 m/s Pfinal Correction: 3 % finite penalty
  - Spin down needed after 3 sigma separation rates
  - -3 sigma Isp used
  - All phasing loop maneuvers are required
    - 70 m/s total
    - 30 m/s of the 70 m/s is at the final perigee maneuver

“Worst case 4 thrusters” Budget

	PROPELLANT		IMPULSIVE DELTA-V		DURATION		THRUSTERS USED	
Spin down propellant	0.07	kg	N/A	m/s	0.55	min	as required	thrusters
One shot thruster tests	0.03	kg	N/A	m/s	0.27	min	all 8	thrusters
"+X cal burn" inertial	1.11	kg	2.5	m/s	2.03	min	4 yaw	thrusters
"-Z cal burn" inertial	0.66	kg	1.5	m/s	2.46	min	2 roll	thrusters
"+Z cal burn" inertial	0.51	kg	1	m/s	2.22	min	2 pitch	thrusters
"+X cal burn" CQT	1.11	kg	2.5	m/s	2.18	min	4 yaw	thrusters
"-Z cal burn" CQT	0.66	kg	1.5	m/s	2.63	min	2 roll	thrusters
"+Z cal burn" CQT	0.51	kg	1	m/s	2.38	min	2 pitch	thrusters
A1 maneuver	0	kg	0	m/s	0	min	4 yaw	thrusters
P1 maneuver	0	kg	0	m/s	0	min	4 yaw	thrusters
A2 maneuver	0	kg	0	m/s	0	min	4 yaw	thrusters
P2 maneuver	0	kg	0	m/s	0	min	4 yaw	thrusters
A3 maneuver	0	kg	0	m/s	0	min	4 yaw	thrusters
P3 maneuver	0	kg	0	m/s	0	min	4 yaw	thrusters
A4 maneuver	0	kg	0	m/s	0	min	4 yaw	thrusters
P4 maneuver	19.11	kg	40	m/s	50.3	min	4 yaw	thrusters
A5 maneuver	0	kg	0	m/s	0	min	4 yaw	thrusters
P5 maneuver	14.25	kg	30	m/s	51.43	min	4 yaw	thrusters
Pfinal correction manuever	6.77	kg	15	m/s	28.51	min	4 yaw	thrusters
Mid course correction maneuver	5.01	kg	10	m/s	52.09	min	2 pitch	thrusters
Shadow avoidance 1 year 1	2.5	kg	5	m/s	27.21	min	2 pitch	thrusters
Stationkeeping @ L2 (month 0 to 3)	0.5	kg	1	m/s	5.54	min	2 pitch	thrusters
Stationkeeping @ L2 (month 4 to 6)	0.5	kg	1	m/s	5.57	min	2 pitch	thrusters
Shadow avoidance 2 year 1	2.5	kg	5	m/s	28.29	min	2 pitch	thrusters
Stationkeeping @ L2 (month 7 to 9)	0.5	kg	1	m/s	5.75	min	2 pitch	thrusters
Stationkeeping @ L2 (month 10 to 12)	0.5	kg	1	m/s	5.78	min	2 pitch	thrusters
Shadow avoidance 1 year 2	2.49	kg	5	m/s	29.36	min	2 pitch	thrusters
Stationkeeping @ L2 (month 13 to 15)	0.5	kg	1	m/s	5.96	min	2 pitch	thrusters
Stationkeeping @ L2 (month 16 to 18)	0.5	kg	1	m/s	5.99	min	2 pitch	thrusters
Shadow avoidance 2 year 2	2.49	kg	5	m/s	30.42	min	2 pitch	thrusters
Stationkeeping @ L2 (month 19 to 21)	0.5	kg	1	m/s	6.17	min	2 pitch	thrusters
Stationkeeping @ L2 (month 22 to 24)	0.5	kg	1	m/s	6.2	min	2 pitch	thrusters
Total Propellant needed	63.78	kg						
Unusable propellant	1.23	kg						
Usable propellant remaining	7.56	kg						
End of life tank pressure	78	psia						
Approximate delta-V remaining	18	m/s						

"Worst case 2 thrusters"

- "Worst case 2 thrusters" is a worst-case trajectory
  - Uses all Delta-V required in the MSMR Rev. 12
- Key "Worst case 2 thrusters" assumptions:
  - A thruster has failed, so all maneuvers use 2 thruster delta-V mode
  - "Worst case" finite burn penalties applied to phasing loop maneuvers as follows:
    - 40 m/s maneuver: 23 % finite penalty
    - 30 m/s Pfinal maneuver: 25 % finite penalty
    - 15 m/s Pfinal Correction: 11 % finite penalty
  - Spin down needed after 3 sigma separation rates
  - -3 sigma Isp used
  - All phasing loop maneuvers are required
    - 70 m/s total
    - 30 m/s of the 70 m/s is at the final perigee maneuver

“Worst case 2 thrusters” Budget

Flight Operations Review

	PROPELLANT		IMPULSIVE DELTA-V		DURATION		THRUSTERS USED	
Spin down propellant	0.07	kg	N/A	m/s	0.55	min	as required	thrusters
One shot thruster tests	0.03	kg	N/A	m/s	0.27	min	all 8	thrusters
"+X cal burn" inertial	1.11	kg	2.5	m/s	2.03	min	4 yaw	thrusters
"-Z cal burn" inertial	0.66	kg	1.5	m/s	2.46	min	2 roll	thrusters
"+Z cal burn" inertial	0.51	kg	1	m/s	2.23	min	2 pitch	thrusters
"+X cal burn" CQT	1.1	kg	2.5	m/s	1.18	min	4 yaw	thrusters
"-Z cal burn" CQT	0.66	kg	1.5	m/s	2.64	min	2 roll	thrusters
"+Z cal burn" CQT	0.51	kg	1	m/s	2.38	min	2 pitch	thrusters
A1 maneuver	0	kg	0	m/s	0	min	2 roll	thrusters
P1 maneuver	0	kg	0	m/s	0	min	2 roll	thrusters
A2 maneuver	0	kg	0	m/s	0	min	2 roll	thrusters
P2 maneuver	0	kg	0	m/s	0	min	2 roll	thrusters
A3 maneuver	0	kg	0	m/s	0	min	2 roll	thrusters
P3 maneuver	0	kg	0	m/s	0	min	2 roll	thrusters
A4 maneuver	0	kg	0	m/s	0	min	2 roll	thrusters
P4 maneuver	21.57	kg	40	m/s	115.68	min	2 roll	thrusters
A5 maneuver	0	kg	0	m/s	0	min	2 roll	thrusters
P5 maneuver	16.34	kg	30	m/s	123.4	min	2 roll	thrusters
Pfinal correction manuever	7.22	kg	15	m/s	64.17	min	2 roll	thrusters
Mid course correction maneuver	5	kg	10	m/s	55.19	min	2 pitch	thrusters
Shadow avoidance 1 year 1	2.5	kg	5	m/s	28.75	min	2 pitch	thrusters
Stationkeeping @ L2 (month 0 to 3)	0.5	kg	1	m/s	5.84	min	2 pitch	thrusters
Stationkeeping @ L2 (month 4 to 6)	0.5	kg	1	m/s	5.87	min	2 pitch	thrusters
Shadow avoidance 2 year 1	2.5	kg	5	m/s	29.81	min	2 pitch	thrusters
Stationkeeping @ L2 (month 7 to 9)	0.5	kg	1	m/s	6.05	min	2 pitch	thrusters
Stationkeeping @ L2 (month 10 to 12)	0.5	kg	1	m/s	6.08	min	2 pitch	thrusters
Shadow avoidance 1 year 2	2.49	kg	5	m/s	30.86	min	2 pitch	thrusters
Stationkeeping @ L2 (month 13 to 15)	0.5	kg	1	m/s	6.26	min	2 pitch	thrusters
Stationkeeping @ L2 (month 16 to 18)	0.5	kg	1	m/s	6.29	min	2 pitch	thrusters
Shadow avoidance 2 year 2	2.49	kg	5	m/s	31.9	min	2 pitch	thrusters
Stationkeeping @ L2 (month 19 to 21)	0.5	kg	1	m/s	6.47	min	2 pitch	thrusters
Stationkeeping @ L2 (month 22 to 24)	0.5	kg	1	m/s	6.5	min	2 pitch	thrusters
Total Propellant needed	68.76	kg						
Unusable propellant	1.23	kg						
Usable propellant remaining	2.58	kg						
End of life tank pressure	73	psia						
Approximate delta-V remaining	7	m/s						

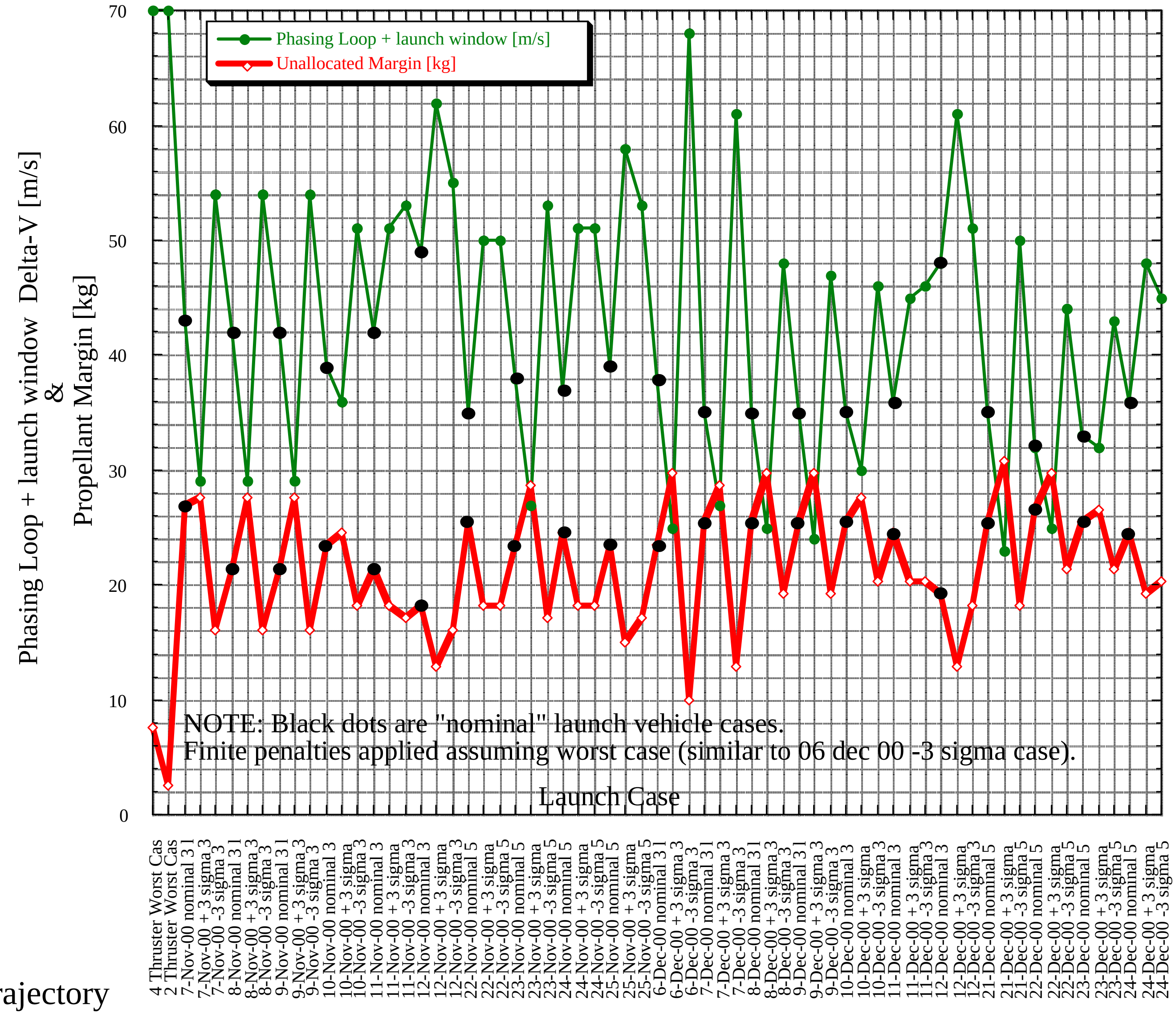
“Reference case”

- “Reference case” uses a nominal 7 Nov 00 launch trajectory
  - Only phasing loop maneuvers are P1 (25.5 m/s) and P3 (8.5 m/s)
- Key “Reference case” assumptions:
  - Finite burn penalties applied to phasing loop maneuvers as follows:
    - 25.5 m/s P1 maneuver: 3 % finite penalty
    - 8.5 m/s P3 maneuver: no finite penalty
    - 15 m/s Pfinal Correction: 1 % finite penalty
  - No spin down needed after separation
  - Nominal Isp used
  - Pfinal (15 m/s) and MCC (10 m/s) correction maneuvers are included

“Reference case” Budget

	PROPELLANT		IMPULSIVE DELTA-V		DURATION		THRUSTERS USED	
Spin down propellant	0	kg	N/A	m/s	0	min	as required	thrusters
One shot thruster tests	0.03	kg	N/A	m/s	0.28	min	all 8	thrusters
"+X cal burn" inertial	1.08	kg	2.5	m/s	2.02	min	4 yaw	thrusters
"-Z cal burn" inertial	0.64	kg	1.5	m/s	2.45	min	2 roll	thrusters
"+Z cal burn" inertial	0.49	kg	1	m/s	2.22	min	2 pitch	thrusters
"+X cal burn" CQT	1.08	kg	2.5	m/s	2.17	min	4 yaw	thrusters
"-Z cal burn" CQT	0.64	kg	1.5	m/s	2.62	min	2 roll	thrusters
"+Z cal burn" CQT	0.49	kg	1	m/s	2.37	min	2 pitch	thrusters
A1 maneuver	0	kg	0	m/s	0	min	4 yaw	thrusters
P1 maneuver	11.26	kg	25.463	m/s	27.74	min	4 yaw	thrusters
A2 maneuver	0	kg	0	m/s	0	min	4 yaw	thrusters
P2 maneuver	0	kg	0	m/s	0	min	4 yaw	thrusters
A3 maneuver	0	kg	0	m/s	0	min	4 yaw	thrusters
P3 maneuver	3.64	kg	8.504	m/s	10.64	min	4 yaw	thrusters
A4 maneuver	0	kg	0	m/s	0	min	4 yaw	thrusters
P4 maneuver	0	kg	0	m/s	0	min	4 yaw	thrusters
A5 maneuver	0	kg	0	m/s	0	min	4 yaw	thrusters
P5 maneuver	0	kg	0	m/s	0	min	4 yaw	thrusters
Pfinal correction manuever	6.48	kg	15	m/s	20.9	min	4 yaw	thrusters
Mid course correction maneuver	4.89	kg	10	m/s	39.92	min	2 pitch	thrusters
Shadow avoidance 1 year 1	2.44	kg	5	m/s	21.15	min	2 pitch	thrusters
Stationkeeping @ L2 (month 0 to 3)	0.49	kg	1	m/s	4.33	min	2 pitch	thrusters
Stationkeeping @ L2 (month 4 to 6)	0.49	kg	1	m/s	4.36	min	2 pitch	thrusters
Shadow avoidance 2 year 1	2.44	kg	5	m/s	22.26	min	2 pitch	thrusters
Stationkeeping @ L2 (month 7 to 9)	0.49	kg	1	m/s	4.54	min	2 pitch	thrusters
Stationkeeping @ L2 (month 10 to 12)	0.49	kg	1	m/s	4.58	min	2 pitch	thrusters
Shadow avoidance 1 year 2	2.44	kg	5	m/s	23.35	min	2 pitch	thrusters
Stationkeeping @ L2 (month 13 to 15)	0.49	kg	1	m/s	4.76	min	2 pitch	thrusters
Stationkeeping @ L2 (month 16 to 18)	0.49	kg	1	m/s	4.79	min	2 pitch	thrusters
Shadow avoidance 2 year 2	2.43	kg	5	m/s	24.41	min	2 pitch	thrusters
Stationkeeping @ L2 (month 19 to 21)	0.49	kg	1	m/s	4.98	min	2 pitch	thrusters
Stationkeeping @ L2 (month 22 to 24)	0.49	kg	1	m/s	5.01	min	2 pitch	thrusters
Total Propellant needed	44.39	kg						
Unusable propellant	1.23	kg						
Usable propellant remaining	26.95	kg						
End of life tank pressure	101	psia						
Approximate delta-V remaining	58	m/s						

All Trajectories vs. Prop. Budget



Trajectories Statistics

- All cases include:
  - 10 m/s launch window, maximum tip-off, 10 m/s calibrations, 15 m/s Pf correction, 10 m/s MCC, 20 m/s shadow avoidance, 2 years stationkeeping, finite penalties, launch vehicle dispersions as appropriate
- The 06 Dec 00 -3 sigma case uses the most propellant:
  - It has the largest trajectory ΔV of 68.1 m/s (with launch window)
  - P1 maneuver of 40.9 m/s is the largest overall maneuver
  - 9.0 kg of unallocated margin for this case
- "Typical" unallocated margin for all cases: 21.7 kg
- "Typical" unallocated margin for all nominal cases: 22.6 kg

Margin Assessment

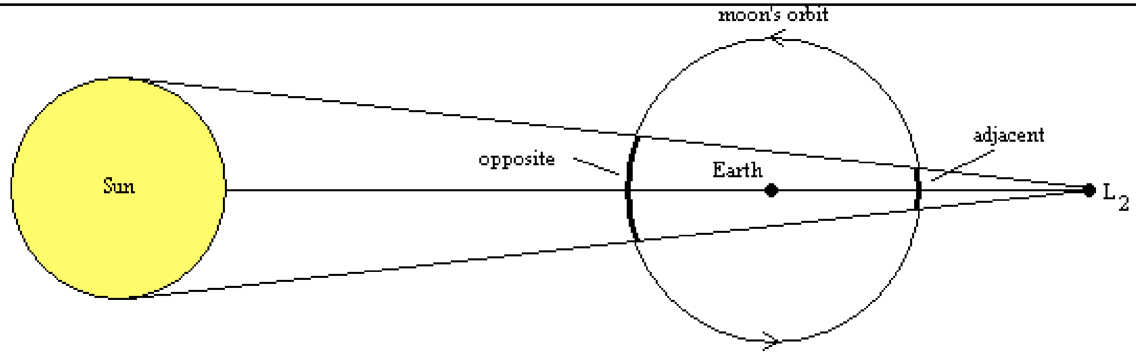
- Potential “Takers” of Unallocated Margin:
  - Missed / Aborted Maneuver
  - Moving maneuver away from perigee for:
    - ACS attitude constraints
    - COMM ground station / TDRS constraints
  - Launch vehicle dispersions > 3 sigma
  - Thruster failure
  - Shadow avoidance in phasing loops
  - Adverse impacts of calibration maneuvers to orbit
- Potential Margin Recovery Options:
  - Eliminate Shadow Avoidance at L2 (20 m/s)
  - Shorten Launch Window (10 m/s)
  - Pf correction (15 m/s) and MCC (10 m/s) [May NOT be an option.]
  - Shorten calibration burns [Use minimum ACS stability duration.]
- We need to quantify margin takers and recoveries

Propellant Budget Summary

- ΔV Requirements are documented in MSMR Rev. 12
- ΔV Requirements are understood by the Project and ACS, propulsion & trajectory teams
- Propellant budget assumptions are conservative
  - Worst case thruster performance and cant angles
  - ACS and finite burn penalties
  - Pfinal & MCC correction maneuvers are included in every budget
  - 2 years of L2 stationkeeping
  - 2 years of shadow avoidance maneuvers
- “Worst case 4 thruster” budget has 7.6 kg of margin
- “Worst case 2 thruster” budget has 2.6 kg of margin
- All trajectories meet ΔV requirements and have unallocated margin which is ≥ 9 Kg (20 m/s)
- “Takers” and recovery options for margin need further analysis

L2 Lunar Shadows

- There appears to be no way to absolutely guarantee that MAP will not face the possibility of a lunar shadow in the L2 orbit strictly through the use of the phasing loop maneuvers
- The analytical model below was an attempt to bound the potential lunar shadow



- **Adjacent - maximum duration 6 hours; maximum depth 13 %**
- **Opposite - maximum duration 8 hours; maximum depth 4.5 %**

- Of cases seen so far, the lunar shadows occur about once per year with an average duration of 4.5 hours and and average depth of 5%

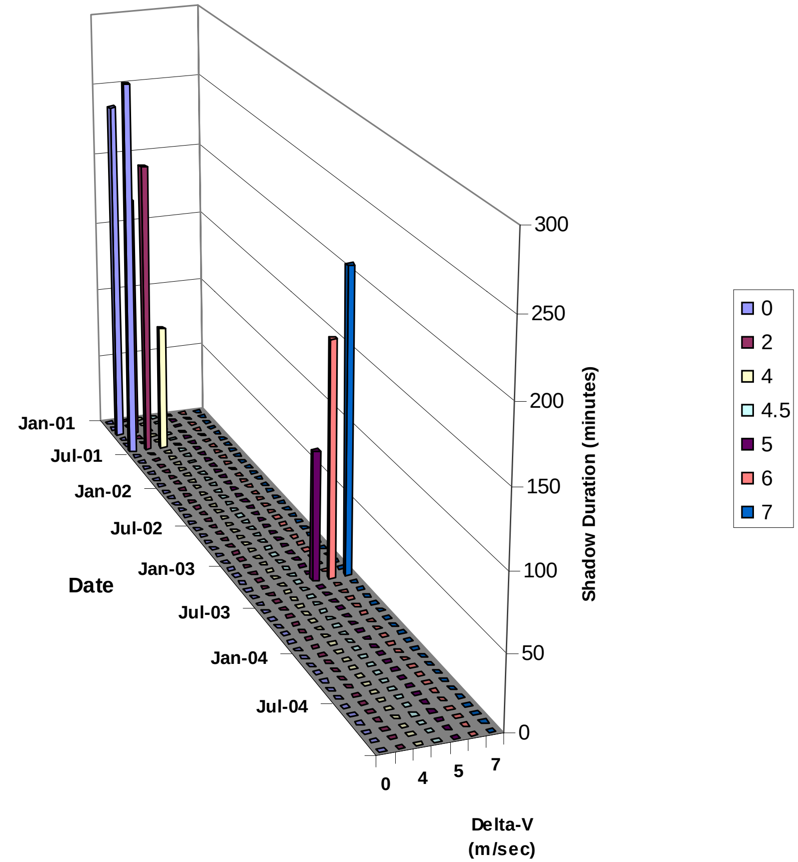
L2 Lunar Shadow Mitigation

- There are several options for mitigation
  - Do nothing
    - schedule stationkeeping maneuver to occur during a lunar shadow
    - fly through the shadow adjusting the attitude to minimize thermal disruption
  - Perform a lunar shadow avoidance maneuver
    - can be performed as part of the post-swingby mid-course correction
    - can possibly be performed in conjunction with an already scheduled stationkeeping maneuver
    - can be performed as an extra maneuver

L2 Lunar Shadow Avoidance Maneuvers

Flight Operations Review

- A sample analysis was performed in an attempt to characterize the size of a lunar shadow avoidance maneuver
  - MCC maneuver (along orbit normal) : 4.5 m/s
  - Downstream shadow avoidance at L2: 4.0 m/s
- Caution must be taken to avoid eliminating one shadow while incurring another shadow further downstream



Phasing Loop Lunar Shadow Avoidance

- Analysis of varying launch times shows minimal encounters with shadows during phasing loops
- Phasing loop shadow avoidance maneuvers impractical
  - such maneuvers must adjust timing to avoid the lunar shadow
  - these maneuvers generally act against maneuvers needed to achieve desired lunar encounter
    - delta-V cost grows
- Strategy is to fly through any lunar shadows encountered during the phasing loops
  - MAP has generous power capabilities - can survive up to 36% occultation indefinitely

Launch Window

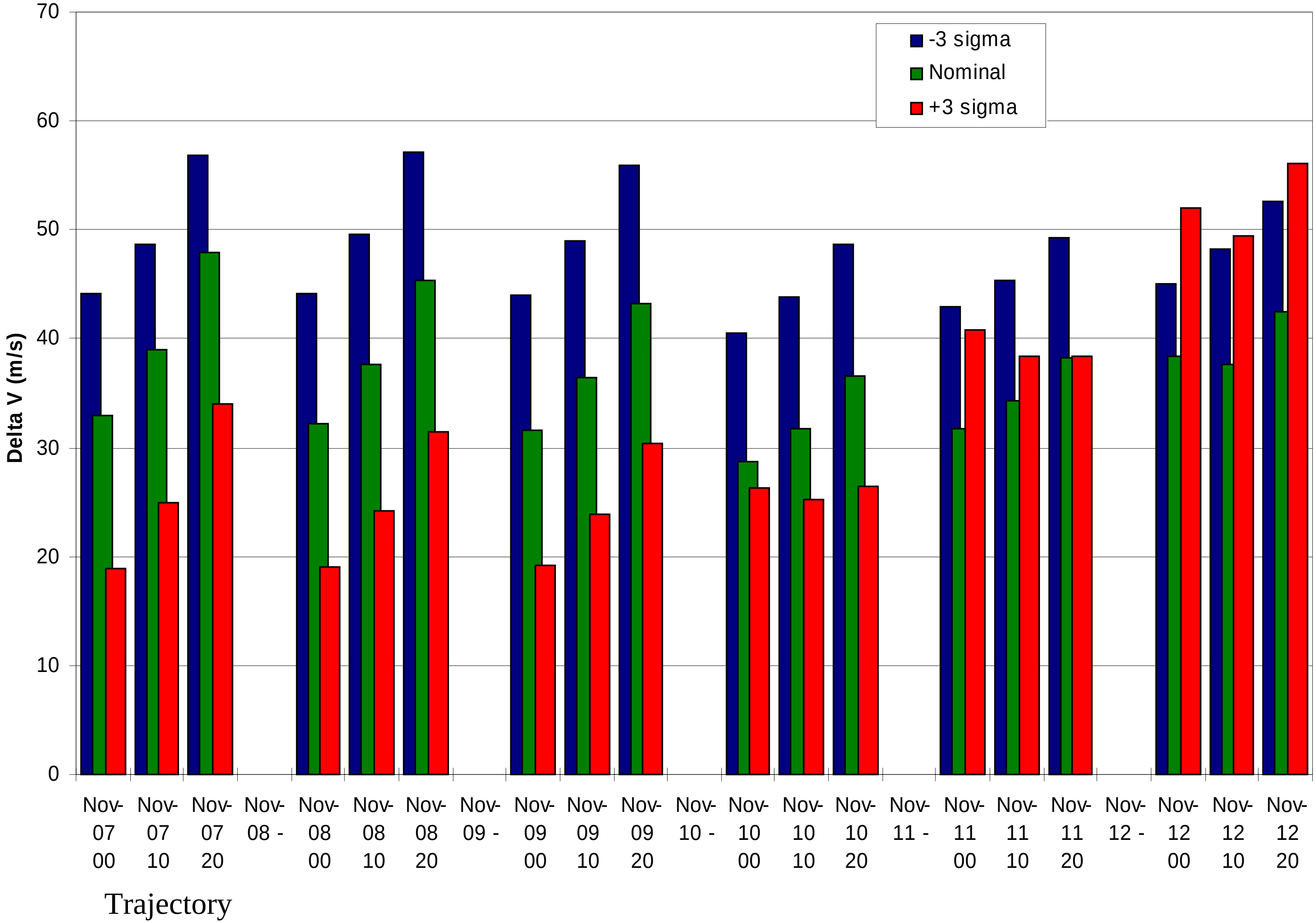
Launch Window

- Scheduled to Launch November 7, 2000 from KSC on a Delta II ELV
- Only about 10 days each month meet mission requirements
- Goal is to open the daily launch window with an additional 10 m/s
- Will examine expanding directions daily launch window in both directions (with respect to trajectories delivered to Boeing)

Daily Launch Window Design

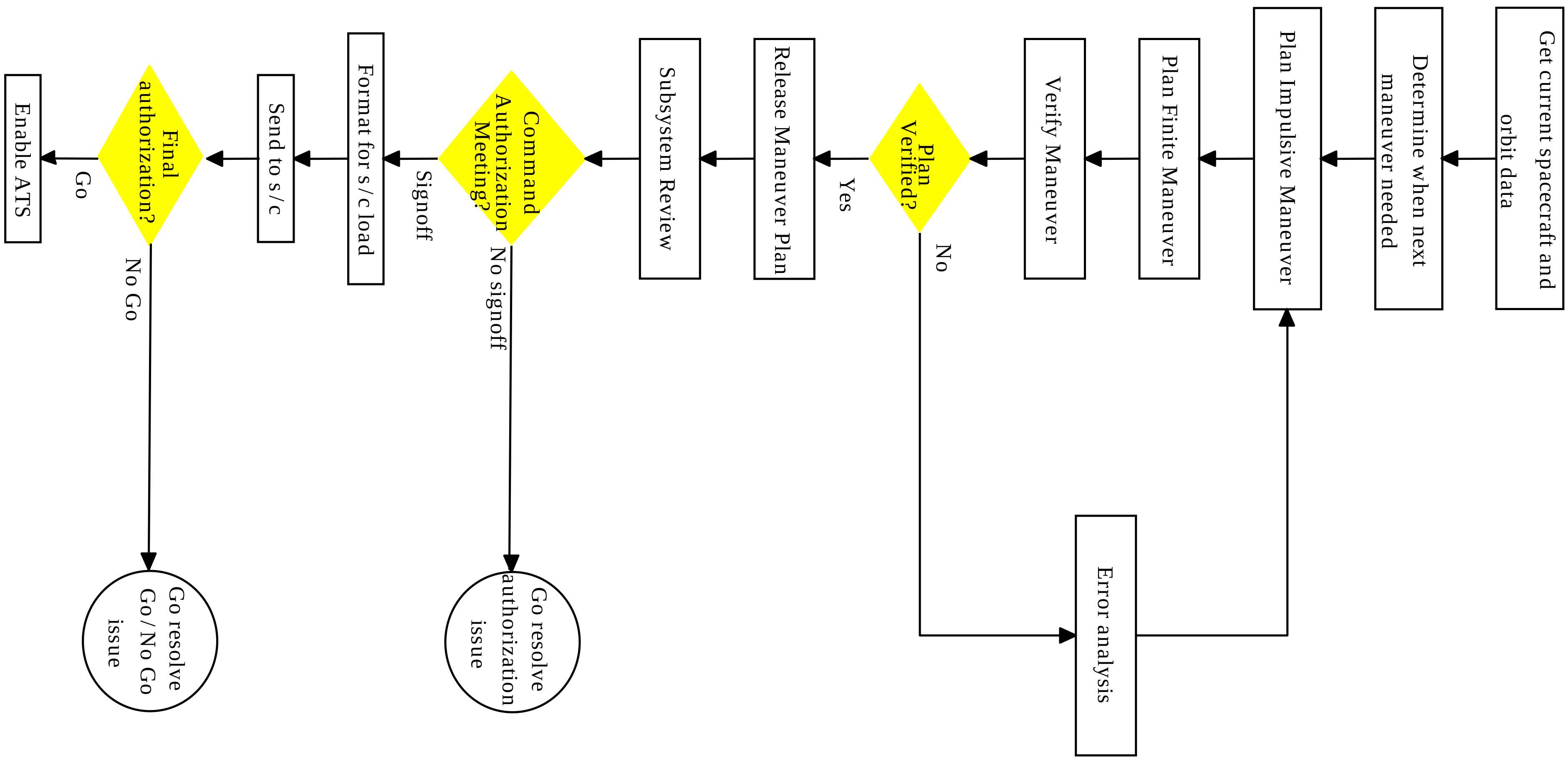
- Work is continuing on developing a finite daily launch window
- Preliminary Status
  - November 3-loop cases: have extended the window forward 20 minutes to examine ΔV costs (up to 15 m/s)
  - December 3-loop cases:
    - December 6: < 5 minutes
    - Have yet to examine remaining cases
  - Have yet to examine 5-loop cases
  - Must verify all constraints
  - Examine opening the window earlier
- Preliminary launch window is due to Boeing in June with a final delivery in October

Preliminary Launch Window Analysis



Maneuver Operations

Maneuver Operations/Decision Flow



Maneuver Approval Process

- Verify maneuver plan
  - validate post-maneuver orbit, fuel usage
  - release Maneuver Planning Sheet

- Command Authorization Meeting
  - subsystem and project signoff
  - authorize load to spacecraft
  - Signoff Maneuver Planning Sheet

- Final Authorization
  - ops, subsystem, project Go/NoGo
  - authorize command enable

Maneuver Ops Timeline

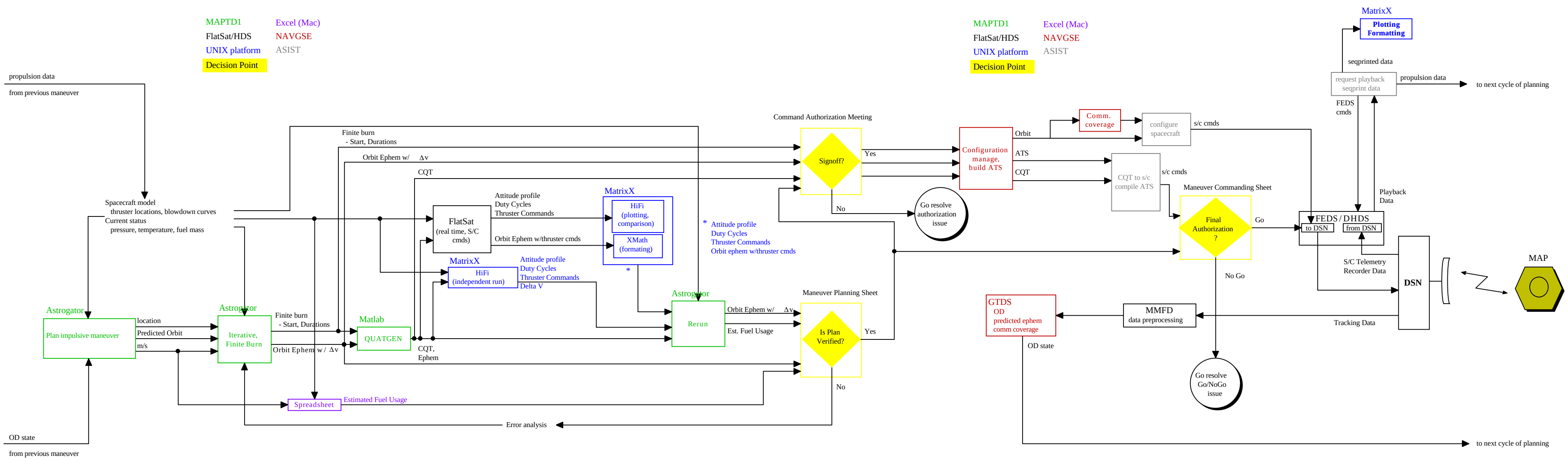
Event	Time	Notes
Collect Tracking data from DSN	M-4 days to M-1 day	37 minutes of tracking per day (Range and Doppler)
Orbit Determination is completed	M-24 hr	
Preliminary Maneuver Plan completed	M-16 hr	Impulse mnvr modeling
Deliver plan to the SMOC	M-15.5 hr	Deliver to JPL (?)
Final Preburn Tracking for planning purposes	M-12 hr to M-8 hr	
OD solution is done	M-7 hr	Final preburn solution
Final Mnvr Plan completed	M-5 hr	
Meet with the SMOC to discuss plan	M-4.5 hr	For Approval
Deliver plan to JPL Nav	M-4 hr	Predicted post burn vector or equivalent
Deliver maneuver parameters	M-3 hr	Start, duration, pred post burn vector and CQT/Commanded Attitude
Load to spacecraft	M-2 hr	ATS, CQT/Commanded Attitude

Maneuver Ops Timeline (cont.)

Event	Time	Notes
Final authorization	M-1 hour	Enable ATS
ACS mnvr to burn attitude	M-30 min	Monitor RT telemetry if available
Maneuver	M	Duration up to 85 min Monitor RT tlm and tracking data is available
ACS slew to scan angle of 22.5 deg off Sun line	End of M + 15 min	Monitor telemetry
Preliminary evaluation of the maneuver	M + 30 min	Based on tlm and Doppler Data
OD solution completed	M + 1 hr	OD done every 30 min until M+8 hr
Mnvr Evaluation/Preliminary Plan for next maneuver	M + 2 hr	Final preburn solution
Maneuver Evaluation	M + 9 hr	Inform MOC
Final maneuver evaluation, preliminary maneuver plan	M + 1 day	Accelerated schedule for Pf correction

Maneuver Information Flow

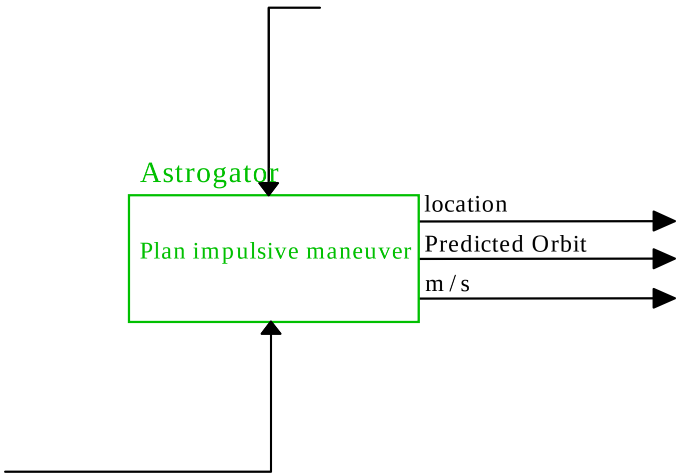
Flight Operations Review



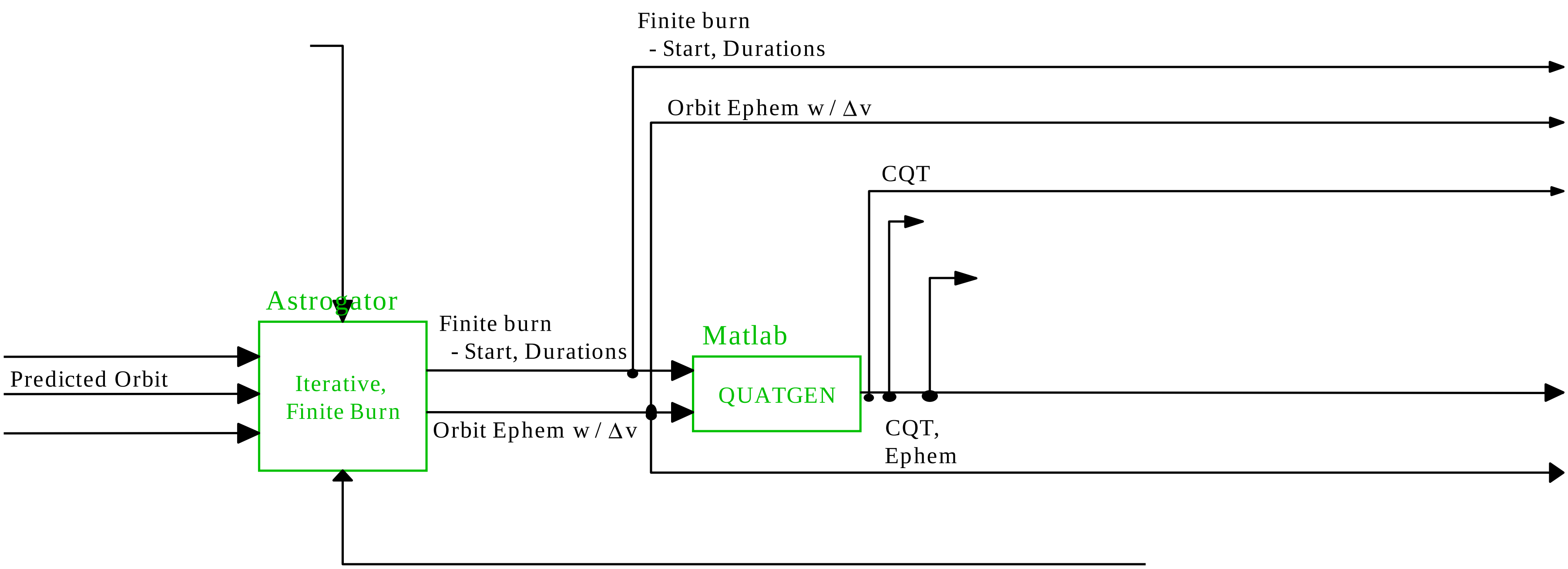
Impulsive | Plan Finite Maneuver | Verification | C. A. M. / Plan Verified | Format / O. D. | Send to s/c / Format | Go/No Go | Analysis / Save data / Cmd to s/c / tlm from s/c / playback

Trajectory

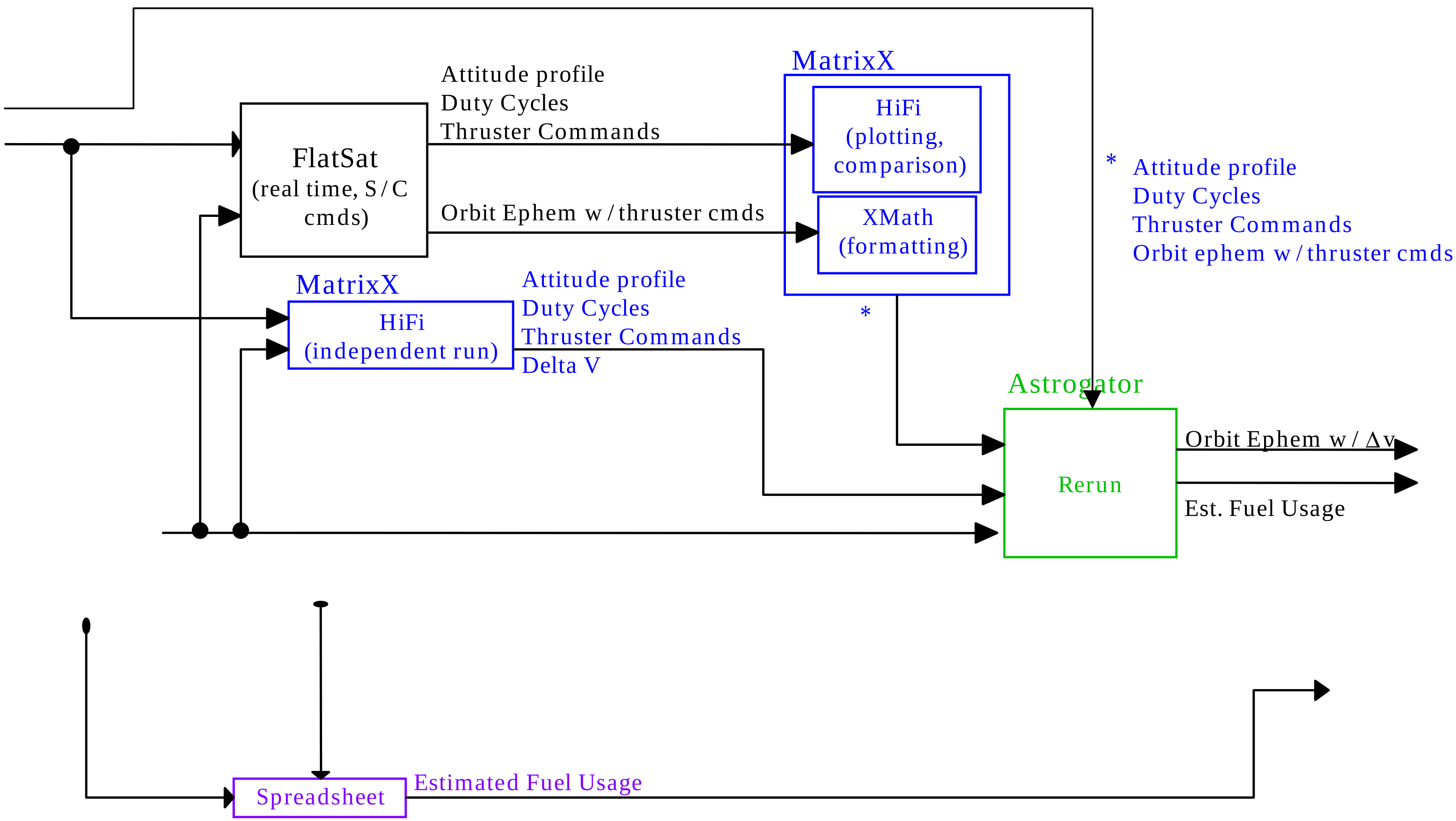
Plan Impulsive Maneuver



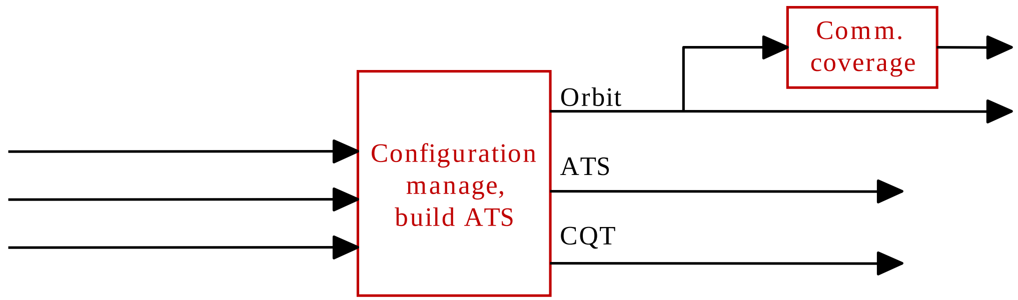
Plan Finite Maneuver



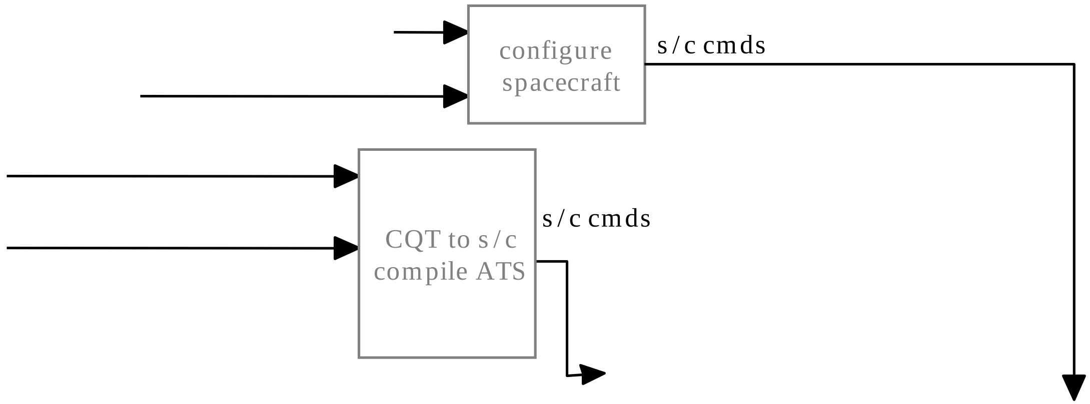
Verify Maneuver



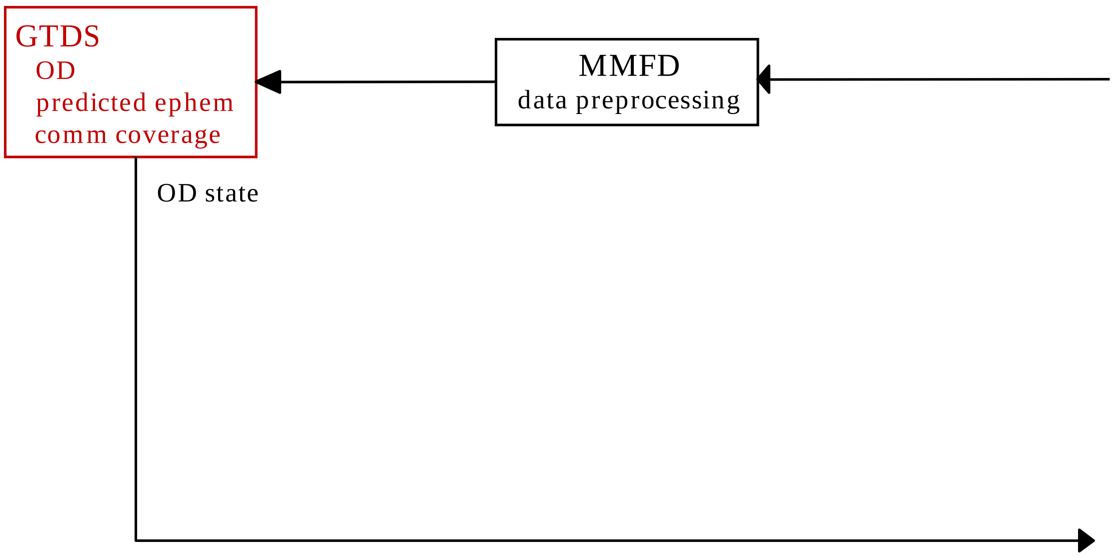
Format for Spacecraft (NAVGSE)



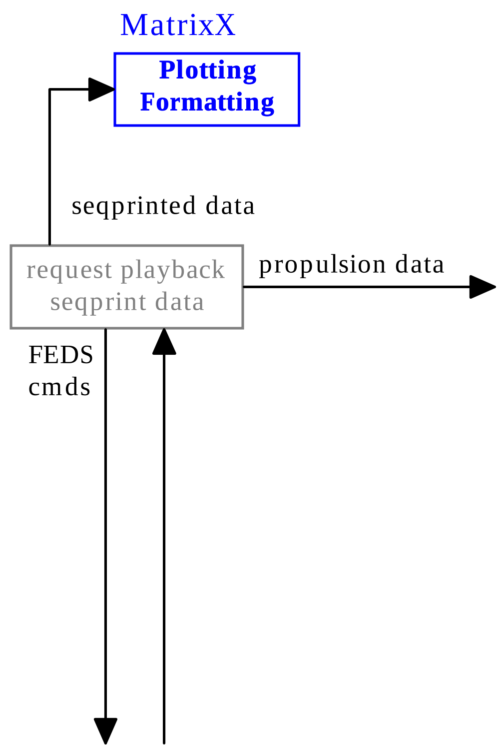
Configure and send data to spacecraft (ASIST)



Orbit Determination (NAVGSE)



Maneuver Analysis



Analytical Tool Status

- STK/Astrogator (AGI)
  - impulsive and finite burn modeling, trajectory design, constraint checking
  - prime maneuver team member: Mike Mesarch (maneuver planning)
  - others for design, contingency analysis, shadow predicts, etc.
- Matlab (The Mathworks)
  - general purpose computation, visualization, programming language
  - QUATGEN - MAP attitude generation module
    - Author: Rick Harman
    - some algorithms from Steve Andrews
  - prime maneuver team member: Harman, Mesarch, Andrews

Analytical Tool Status (cont.)

- MatrixX (ISI)
  - general purpose computation, visualization, programming language (Xmath)
    - can be used to ingest formatted spacecraft telemetry
      - detailed attitude profile, duty cycle, etc
      - thruster command pulses --> fuel budget tracking
  - block-diagram simulation editor (SystemBuild)
  - automatic code generation (AutoCode)
  - automatic documentation (DocumentIt)
  - HiFi (high fidelity ACS modeling, simulation and analysis)
    - Author: Jim O'Donnell
    - input from many other team members
  - prime maneuver team member: Steve Andrews
- Excel (Microsoft)
  - fuel budget
  - author and prime maneuver team member: Gary Davis

Analytical Tool Status (cont.)

- NAVGSE
  - The MAP Navigation Ground Support Equipment (NAVGSE) is a software robot
    - MIDEX Ground System Equipment written in LabVIEW
    - running on one or more Microsoft NT 4.0 workstations
    - controlled by and reports status to ASIST
    - can be operated from the GSE front panel as with the other MIDEX GSE.
  - author and prime maneuver team member: Dale Fink

Analytical Tool Status (cont.)

- NAVGSE (cont.)

Function	Application	Connections
Tracking Data Collection	LabVIEW	MMFD, ASIST
Orbit Determination	GTDS	ASIST
Schedule Input Generation	STK	ASIST
Schedule Input Delivery	LabVIEW	MOPSS
Ephemeris Generation	GTDS	ASIST
Ephemeris Delivery	LabVIEW	ASIST, MOPSS, MMFD
RT Attitude Determination	Matlab	ASIST
Offline Attitude Determination	Matlab	ASIST
Maneuver ATS Generation	STK, Matlab	ASIST
Maneuver ATS Delivery	LabVIEW	ASIST, MOPSS
Online Documentation	LabVIEW	Internet
Online Status Reporting	LabVIEW	ASIST, SERS, Internet

Software Verification

- HiFi & FlatSat verified in flight software build and acceptance testing
- STK/Astrogator verified against Swingby (operations heritage)
- plan to verify STK/Astrogator against FlatSat and HiFi
- summary of performance so far
  - HiFi and FlatSat agree when plotted against each other
    - minor differences from higher fidelity orbit propagator in HDS, and timing differences between real-time system (FlatSat) and all-software system (HiFi)
  - HiFi and Astrogator have some discrepancies
    - some due to known differences in current models
      - will be eliminated with use of configured database
    - remaining errors will be evaluated once the main differences are removed

Orbit Maneuver Execution

- Before phasing loop maneuver
  - Command Quaternion Table (CQT) loaded to flight software
  - appropriate table values loaded
  - reconfigure FDC
  - configure downlink and telemetry tables
  - spin down from Observing Mode
  - command to Inertial Mode
  - enable CQT
  - turn on cat bed heaters
  - power thrusters (through LVPC)
  - enable thrusters
  - ground allows Delta V command to be executed

Orbit Maneuver Execution

- After phasing loop maneuver
  - shut off cat bed heaters
  - unpower thrusters (through LVPC)
  - disable thrusters
  - disable CQT
  - reset Kalman filter
  - slew to scan angle
  - reset tables and telemetry rate

Orbit Maneuver Execution

- Before L_2 maneuver
  - appropriate table values loaded
  - reconfigure FDC
  - configure downlink and telemetry tables
  - spin down from Observing Mode
  - command to Inertial Mode
  - command burn attitude (20° off sunline)
  - turn on cat bed heaters
  - power thrusters (through LVPC)
  - enable thrusters
  - ground allows Delta V command to be executed

Orbit Maneuver Execution

- After L_2 maneuver
  - shut off cat bed heaters
  - power off thrusters (through LVPC)
  - disable thrusters
  - reset Kalman filter
  - slew to scan angle
  - reset tables and telemetry rate

Phasing Loop ATS

- **items in** bold **are required from flight dynamics team before maneuver**
- **burnstart format: burnstart = 00-320-01:33:55.731**

```
CMDN = 1

wait until burnstart+\-00:45:00.000 ; burn -45 minutes
/MSCSTARTR RTS = 152                ; configure for 2k downlink
                                    ; for TDRS contacts

wait until burnstart+\-00:42:00.000 ; burn -42 minutes
/MDSCHGFILTER tableid = 2           ; change DS to Engineering tables

wait until burnstart+\-00:40:00.000 ; burn -40 minutes
/ACSSPINDOWN                        ; spin down from Observing Mode

wait until burnstart+\-00:35:00.000 ; burn -35 minutes
/ACSGOINERTIAL                      ; go to Inertial Mode

wait until burnstart+\-00:30:00.000 ; burn -30 minutes
/ACSCQTCFG ENA NOTCONSTRAINED DONOTUSEPREV ; enable use of CQT with no sun
                                           ; constraint, use next entry
```

Phasing Loop ATS (cont.)


```
wait 1
/MSCENAR RTS = 154                    ; enable RTS 154
wait 1
/MSCSTARTR RTS = 154                  ; turn-on CatBed Htrs
wait 1
/ALSERVON ALVPCON = x'100'            ; power thrusters

wait until burnstart+\-00:05:00.000                      ; burn -5 minutes
/ACEGRDFIREENA T1=1, T2=1, T3=1, T4=1, T5=1, T6=1, T7=1, T8=1 ; enable thrusters

wait until burnstart                  ; command burn, durations in seconds
/ACSGODELTAV XDURATION = 1090.314 ZDURATION = 0.000 ; 18 min 10.314 sec

wait until burnstart+\+00:23:10.314 ; end-of-burn +5 min allowing Delta H and
                                      ; subsequent Inertial Mode settling
/MSCSTARTR RTS = 155                  ; post-burn configuration (thruster
                                      ; driver & CatBeds Off)
wait 1
/ACEGRDFIREENA T1=0, T2=0, T3=0, T4=0, T5=0, T6=0, T7=0, T8=0 ;disable thrusters
```

Phasing Loop ATS (cont.)

```
wait until burnstart+\+00:28:10.314 ; end of burn +10 minutes
/ACSCQTDISABLE                      ; disable CQT
wait 1
/ACSRESETKALMAN                     ; reset Kalman filter

wait until burnstart+\+00:33:10.314 ; end-of-burn +15 minutes
/ACSSLEWSCANANGLE                   ; slew to 22.5 deg off sunline

wait until burnstart+\+00:48:10.314 ; end-of-burn +30 minutes
/MDSCHGFILTER tableid = 1           ; change DS to Mission Tables, select nominal
                                    ; tables
wait 1
/MSCSTARTR RTS = 156                ; close all datasets, R/T Pass #2
```

CQT

- CQT data generated by MAP Quaternion Generation program
  - MATLAB .m file
  - Author: Rick Harman, Code 572
    - some initial algorithms from S. Andrews
    - testing and other inputs and algorithms from Trajectory team
  - algorithm will put desired axis on velocity vector, and put z axis close to the sun
    - sunline limited to DSS field of view
    - can adjust “crab” angle to account for 15° thruster cant angles
  - output format determined by format needed by Flight Software CQT
  - output file sent to flight ops team as *procname.prc*
  - time of each quaternion is number of seconds from MAP mission epoch (Jan. 1.0 1993)

CQT format

```
PROC procname
;
;Data taken from MAP ORBIT QUATERNION UTILITY
;First command quaternion is at 20001205.022900000
;
ATCQTRECORDCOUNT = 2
;
ATCQTENTRY[001].STARTTIME = 250136940.000
ATCQTENTRY[001].CMDQ[1] = 8.1264173e-001
ATCQTENTRY[001].CMDQ[2] = 2.3561194e-001
ATCQTENTRY[001].CMDQ[3] = 2.3951258e-001
ATCQTENTRY[001].CMDQ[4] = 4.7616610e-001
;
ATCQTENTRY[002].STARTTIME = 250142036.000
ATCQTENTRY[002].CMDQ[1] = 8.1362377e-001
ATCQTENTRY[002].CMDQ[2] = 2.4264992e-001
ATCQTENTRY[002].CMDQ[3] = 2.3914611e-001
ATCQTENTRY[002].CMDQ[4] = 4.7111199e-001
;
ENDPROC
```

Delta V command

- Trajectory team supplies x and/or z axis burn time in seconds.
- Format:

```
/ACSGODELTAV XDURATION = 5100.000   ZDURATION =    0.000
/ACSGODELTAV XDURATION =    0.000   ZDURATION =   10.123
/ACSGODELTAV XDURATION =    0.000   ZDURATION =  -20.456
/ACSGODELTAV XDURATION =   11.400   ZDURATION =  -21.241
/ACSGODELTAV XDURATION =   20.678   ZDURATION =   30.890
```

- XDURATION is the time to fire thrusters 5, 6, 7, 8 (~x force)
- ZDURATION
  - positive value fires thrusters 3 and 4 (+z force)
  - negative value fires thrusters 1 and 2 (-z force)

Ephemeris Command

- Trajectory team supplies values; POSi are meters, VELi are meters/second, and EPVTIME is seconds since MAP epoch.
- Format:

```
/EPHPROCESSEPHEM POSX =       -3.3990610317E+06 ;;
                 POSY =       -9.2680859657E+06 ;;
                 POSZ =        9.6980013353E+05 ;;
                 VELX =        6.6097123999E+03 ;;
                 VELY =       -4.9372815813E+03 ;;
                 VELZ =        3.1892623074E+03 ;;
                 EPVTIME = 2.4849397533E+08  OPTION
```

- *OPTION* is to enable or disable the continuity check that verifies the new ephemeris is not too far from the current onboard ephemeris.
  - CONTINUITYCHECKENA
  - CONTINUITYCHECKDIS

Commanded Quaternion

- Represents desired spacecraft attitude relative to geocentric inertial reference frame
  - magnitude = 1
  - positive fourth component
- Format:

```
/ACSLOADCMDQUAT Q1 = -2.989288625773139e-01  ;;
                Q2 = -7.487005436993172e-01  ;;
                Q3 =  5.495035049347157e-01  ;;
                Q4 =  2.193967389161544e-01  OPTION
```

- OPTION is to allow a sun constraint to be applied, and reject the commanded attitude if it will put the spacecraft z axis outside of a (nominally) 25° cone about the sunline.
  - CONSTRAINED
  - NOTCONSTRAINED

L_2 ATS

- **items in** bold **are required from flight dynamics team before maneuver**
- **burnstart format: burnstart = 00-320-01:33:55.731**

```
CMDN = 1

wait until burnstart+\-00:45:00.000 ; burn -45 minutes
/MSCSTARTR RTS = 151                 ; configure for 666k downlink

wait until burnstart+\-00:42:00.000 ; burn -42 minutes
/MDSCHGFILTER tableid = 2            ; change DS to Engineering tables

wait until burnstart+\-00:40:00.000 ; burn -40 minutes
/ACSSPINDOWN                         ; spin down from Observing Mode

wait until burnstart+\-00:35:00.000 ; burn -35 minutes
/ACSGOINERTIAL                       ; go to Inertial Mode

wait until burnstart+\-00:30:00.000 ; burn -30 minutes
/ACSSYSRATECHKCFG CHANGEX CHANGEY CHANGEZ DISX DISY DISZ ; disable system rate
                                                         ; check
```

L_2 ATS (cont.)


```
/ACSLOADCMDQUAT Q1 = qcmd1             ;;
                Q2 = qcmd2             ;;
                Q3 = qcmd3             ;;
                Q4 = qcmd4             ;;
                option                 ; option is NOTCONSTRAINED/CONSTRAINED
wait 1
/MSCENAR RTS = 154                     ; enable RTS 154
wait 1
/MSCSTARTR RTS = 154                   ; turn-on CatBed Htrs
wait 1
/ALSERVON ALVPCON = x'100'             ; power thrusters

wait until burnstart+\-00:05:00.000                         ; burn -5 minutes
/ACEGRDFIREENA T1=1, T2=1, T3=1, T4=1, T5=1, T6=1, T7=1, T8=1 ; enable thrusters

wait until burnstart                   ; command burn, durations in seconds
/ACSGODELTAV XDURATION = 0.000 ZDURATION = -100.000 ; 1 minute 40 sec maneuver

wait until burnstart+\+00:06:40.000 ; end-of-burn +5 min allowing Delta H and
                                    ; subsequent Inertial Mode settling
/MSCSTARTR RTS = 155                ; post-burn configuration (thruster
                                    ; driver & CatBeds Off)
```

L_2 ATS (cont.)


```
wait 1
/ACEGRDFIREENA T1=0, T2=0, T3=0, T4=0, T5=0, T6=0, T7=0, T8=0 ;disable thrusters

/ACSSYSRATECHKCFG CHANGEX CHANGEY CHANGEZ ENAX ENAY ENAZ ; enable system rate
                                                         ; check

wait until burnstart+\+00:11:40.000  ; end-of-burn +10 minutes
/ACSRESETKALMAN                      ; reset Kalman filter

wait until burnstart+\+00:16:40.000  ; end-of-burn +15 minutes
/ACSSLEWSCANANGLE                    ; slew to 22.5 deg off sunline

wait until burnstart+\+00:31:40.000  ; end-of-burn +30 minutes
/MDSCHGFILTER tableid = 1            ; change DS to Mission Tables, select nominal
                                     ; tables
wait 1
/MSCSTARTR RTS = 156                 ; close all datasets, R/T Pass #2
```

Post-Maneuver Analysis

- Primary maneuver spacecraft subsystems
  - propulsion
  - ACS
  - trajectory
- Other subsystems
  - instrument
  - power
  - thermal
- “Quick and dirty”
  - page snaps, plot page snaps, spreadsheets

Post-Maneuver Analysis (cont.)

- "Slow and clean"
  - dump recorder, playback and seqprint data (ASIST, DHDS)
  - plotting and detailed analysis (MatrixX, Matlab)
  - maneuver reconstruction (Astrogator)
- Orbit determination
- *Maneuver recalibration*
  - *procedure for recomputing and using a new thrust scale factor is the same as after the initial calibration maneuvers*

Configuration Management

- software modules
  - Matlab
  - STK/Astrogator
  - MatrixX
  - NAVGSE
  - Excel
- products
  - time-stamped filenames
  - database for critical model parameters
    - all software modules should be able to use database output
    - update as needed (project CCR process)

Simulation Plan

- Mission Simulations
  - eight planned, first two completed
  - recently added FlatSat sims
  - maneuver component of future sims:

    FlatSat: push data through planning, ground system, end-to-end, nominal maneuver

    #3: aborted burn, cal burns

    #4: all cal burns, maneuver w/contingency

    FlatSat: push data through planning, ground system, end-to-end, with contingency

    #5: cal burns, maneuver

    FlatSat: push data through planning, ground system, end-to-end, for cal burns, nominal maneuver

    #6: maneuver proficiency and contingency

    #7: maneuver proficiency and contingency

    #8: maneuver proficiency and contingency

Simulation Plan (cont.)

- Internal Maneuver Team Simulations
  - Execute the process from OD product delivery to NAVGSE output
  - Nominal
    - NAVGSE Interface Sim
    - Mid Course Correction
    - P_{final}
    - Stationkeeping Maneuver at L_2
  - Contingency
    - Missing P_1
    - Underburn P_{final}

Mission Sim #2 - Preliminary Results

- Executed Finite maneuver flow during simulation on February 26
- QUATGEN output was uploaded to spacecraft simulator and used to drive the spacecraft attitude
- ACS performance during simulation matched expected behaviors
- Have not fully analyzed all simulation data to do re-construction of maneuver

<u>From February 26 Simulation</u>

	Impulsive (Astrogator)	Finite (Astrogator)	HIFI	FlatSat
ΔV (m/s)	24.463	24.773	24.417	TBD
Δt (s)	1076	1099	X: 1090.32 Z: 0	1073
Δm (kg)	8.93	9.12 (w/o ACS)	9.05	9.13

Orbit Determination Error Analysis

Orbit Determination and Tracking Requirements

Mission Phase	Service	Data Type	Pass Frequency	Definitive OD Requirements (3 σ)	Data Sample Rate	Predicted OD Requirements (3 σ)
LEO (L+0 to L + 1 day)	26-m or 34m	Range and Doppler	Continuous 2 stations for first 12 hours, one station second 12 hours	Best Obtainable	Doppler:1/10sec Range:1/10sec	Position: 25 km
Transfer Trajectory Phase-nominal (2 days-Flyby +3 days) Nominal Support	26-m or 34-m	Doppler, range, and angles from 26-m	2 – 4 one hour passes/day	Position: 5 km Velocity: 5 cm/s	Doppler:1/10sec Range: 1/10sec	Position: 50 km Velocity: 10 cm/s
Transfer Trajectory Phase-maneuvers & lunar gravity assist (phasing loops)	26-m or 34-m	Doppler, range	Near Continuous Man – 12h to Man– 8h (4 hour span) and M start to M+12 hours	Position: 5 km Velocity: 5 cm/s	Doppler:1/10sec Range: 1/60sec	Position: 50 km Velocity: 10 cm/s
Cruise (Gravity Assist to L2 Insertion) (~70 days)	70-m or 34-m	Doppler, range	Nominal: One 37-min pass/day*	Position: 5 km Velocity: 5 cm/s	Doppler:1/10sec Range: 1/60sec	Position: 50 km Velocity: 10 cm/s
Cruise-maneuvers	70-m or 34-m	Doppler, range	Near Continuous M-12 h to M-8 h (4 h span) and M start through M+12 hr	Position: 10 km Velocity: 5 cm/s	Doppler:1/10sec Range: 1/60sec	Position: 50 km Velocity: 10 cm/s
L2-nominal (2 years)	70-m or 34-m	Doppler, range	One 37 min pass/day*	Position: 10 km Velocity: 5 cm/s	Doppler:1/10sec Range: 1/10sec	Position: 50 km Velocity: 10 cm/s
L2-maneuvers Delta V/Delta H	70-m or 34-m	Doppler, range	Near Continuous from M-4 hr to M+4 hr	Position: 10 km Velocity: 5 cm/s	Doppler:1/10sec Range: 1/60sec	Position: 50 km Velocity: 10 cm/s

***alternating N & S hemisphere DSN stations**

Based on the DMR

Orbit Determination Error Analysis

- November 8th trajectory was used to generate station contacts and maneuver states
- Results will provide the Orbit Determination accuracy given available tracking data -- which will affect maneuver accuracy and calibration
- Assumed continuous tracking data before and after maneuvers as documented in the DMR
- At least two stations supporting pre- and post-maneuver OD
- Final covariance analysis results will be completed by the end of April 2000

Orbit Determination Error Analysis (cont)

- Covariance Analysis is underway to analyze several phases of the MAP mission
  - **Maneuver Recovery**
    - Phasing loops (TTI, P1 and Pfinal analysis have been completed. Results will be delivered by the end of March. Preliminary results show:
      - Position error for the 6 and 12 hours solutions are under 5 km
      - Velocity errors for the 6 and 12 hours solutions are under 3 cm/sec
  - **Maneuver Planning**
    - Phasing loops (TTI, P1 and Pfinal maneuver planning) analysis is currently being done. Preliminary results show:
      - Maneuver - 24 hour solution (longer data arcs)
        - » Position errors less than 10 km
        - » Velocity errors less than 10 cm/sec
    - Routine Orbit Determination uncertainties were less than 10km in position and 10cm/sec in velocity
    - L2 stationkeeping maneuver analysis is underway.

Error Analysis

- Impulsive vs finite burn
- Maneuver Execution (Phasing Loop & L2)
  - 5.2% Error (RSS Value)
    - 1% modeling mass uncertainty and Cd offsets
    - 5% thrust - thruster imbalance
    - 1% ACS - Effect of ACS jet firings on orbit (5 deg spec)
- Momentum unload effect on orbit
- Fuel usage and thrust
- Launch vehicle error > 3σ

Contingency Studies

Contingency Philosophy

The main contingency philosophy is:

1. Make the spacecraft safe
   – on-board FDC may have already done this

2. Make the orbit safe
   – may require quick recovery from failure - especially during the phasing loop maneuvers

Contingency Context

- Maneuvers will be monitored on ground.
- Two cases of contingency
  - if something goes wrong that onboard FDC doesn't catch
  - if onboard FDC aborts/prevents maneuver
- Either event will trigger a host of contingency reactions
  - ACS will put spacecraft in safe orientation
  - in parallel, trajectory team will determine whether a quick recovery is needed or not, and start planning next maneuver
  - other groups will be working through their own safing and diagnostic flowcharts

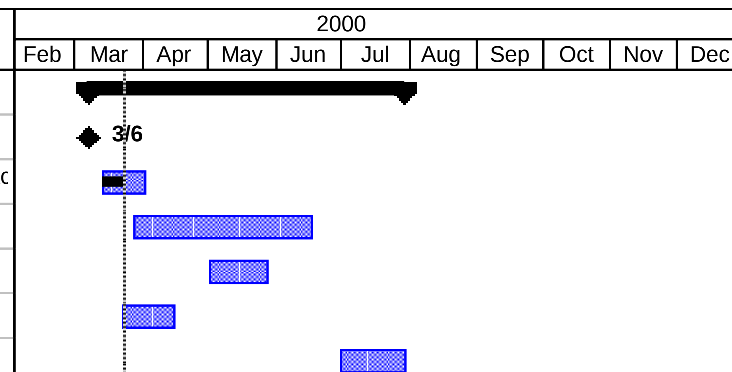
Trajectory Planning Contingency Analysis

- Definition:
  - Characterize Contingency Scenarios w/Sub-system Leads
  - Define and Prioritize Contingency Analyses w/GNCC experts
- Analysis:
  - Defines strategy to recover from contingency
- Six Contingency Analyses Prioritized
  - Missed or partial Perigee 1 - Analysis completed
  - Strategy to move perigee maneuvers into station contact
  - Missed Pf burn (missing all perigees)
  - Thruster failure
  - Split perigee maneuver analysis
  - LV error >3 sigma

Trajectory Planning Contingency Analysis (cont.)

- Approach:
  - Use November 7 Nominal Trajectory
  - Contingency analysis items have been assigned
- Schedule:

ID	Task Name
18	**Contingency Analysis**
19	Missed or partial P1 burn
20	Strategy to move perigee maneuvers into station contac
21	Thruster failure
22	Missed Pf burn (missing all perigees)
23	Split perigee maneuver analysis
24	LV error >3 sigma



Staffing for Operations

Staffing Profile
Launch through MCC + 24 hrs

	L – P1+24h	P1+24h – Pf-48h	Pf-48h – Moon+24h	Moon+24h – MCC–48h	MCC–48h – MCC+24h	MCC+24h – L2
Trajectory	P: 2 analysts B: 2 analysts Shift: 12 hr	P: 1 analysts B: 1 analysts Shift: 8 hr	P: 2 analysts B: 2 analysts Shift: 12 hr	P: 1 analysts B: 2 analysts Shift: 8 hr	P: 2 analysts B: 2 analysts Shift: 12 hr	P: as needed Shift: 8 hr
ACS	P: 3 engineers B: 1.5 engineers Shift: 12 hr	P: 2 engineer B: as needed Shift: 12 hr	P: 2 engineer B: as needed Shift: 12 hr	P: 2 engineer B: as needed Shift: 12 hr	P: 2 engineer B: as needed Shift: 12 hr	P: 1.5 engineer Shift: 8 hr
Propulsion	P: 1 engineer B: 1 engineer Shift: 12 hr	P: 1 engineer B: 1 engineer Shift: 12 hr	P: 1 engineer B: 1 engineer Shift: 12 hr	P: 1 engineer B: 1 engineer Shift: 12 hr	P: 1 engineer B: 1 engineer Shift: 12 hr	P: 1 engineer B: 1 engineer Shift: 8 hr
Navigation						
Flight S/W	←		TBD			→
Controllers						

P: Prime Shift
B: Backup Shift

Schedule

Current Schedule

- PMA - 1 Delivery (Boeing) on Dec 14, 1999
- Trajectory Design Peer Review held on Dec 16, 1999
- Daily Launch Window Analysis completed Feb 1, 2000
- Nov Refinement Using PMA completed Feb 15, 2000
- Dec Refinement Using PMA completed March 1, 2000
- DTO Requirements Were Due Feb 1, 2000
- Leonids Analysis Post 1999 Event completed
- DTO Delivery From Boeing by April 25, 2000
- January Refinement Using PMA due on May 1,2000
- February Refinement Using PMA due on May 31, 2000

Current Schedule (cont'd)

- Stationkeeping Analysis
  - Minimize # of SK maneuvers due by May 31, 2000
  - Momentum Dumps - Impact and Frequency by June 15, 2000
- Daily Launch Window (preliminary) due June 30, 2000
- Daily Launch Window (final) due Oct 10, 2000
- Launch Vehicle Angle Error - Impact Due by June 2000

Current Schedule (cont'd)

- Orbit Covariance Analysis due by March 31, 2000
  - During the phasing loops (maneuver planning and calibration)
  - At L2 (maneuver planning and calibration)
- Procedures on how to use Astrogator (preliminary) due March 31, 2000
- OD error Impact on Maneuver Plan
  - During transfer phase due on Aug 14, 00
  - During the L2/Cruise due June 15, 2000
- Final version of the Ops Procedures due by L-3 months

Future Analysis

- Stationkeeping Analysis
  - Current method
  - Minimize # of SK maneuvers
  - Momentum management impact on Stationkeeping
  - Eigenvector optimization
- Other Analysis
  - Determination of worst case phasing loop shadow analysis.
  - Effect of coast time on station contacts
  - Attitude Control System hang off on orbit analysis
  - Impact on specified attitude control system
  - Impact on specified propulsion system
  - Impact from specified trajectory
  - Characterize sensitivity of shadows
  - Moon Shadow Avoidance Strategy
- Orbit Determination Covariance Analysis
  - Phasing loops and at L2

Future Analysis (cont)

- Orbit Determination Impact on Maneuver Plan
  - During the transfer phase and L2
- Trajectory Design Trends
  - Lunar Perturbations on P1 and P2 altitude/Δv to correct
  - ELV error and B-plane vector magnitude on L2 orbit size
  - Effect of launch coast duration on
    - Daily Launch window
    - Minimizing or avoiding A1 maneuvers
- Moon Shadow Avoidance Strategy
- Earth Shadow Avoidance Strategies If Necessary
- Station Contact Optimization
- Launch Vehicle Pointing Error - Impact on Traj Design

Issues

Issues/Concerns

- Requirement for “No lunar shadows at L2” can not be guaranteed
  - Mitigation: 20 m/s has been allocated for lunar shadow avoidance
  - Complete fuel margin assessment
- Phasing Loop lunar shadow avoidance
  - Does not appear to be a problem

Reliability, Constraints, and Contingencies

Mike Bay

MIDEX Reliability Philosophy

- Reliability Designed in from the Beginning
  - MIDEX Assurance Requirements Cover Total Program:
    - Design with proper parts application
    - Grade 3 Parts program selected as best value for the MIDEX Program
    - Workmanship Inspection program to NHB5300 or equivalent
  - Robust Design providing graceful degradation
  - Failure Modes and Effects Analysis used to identify mission ending failures, designs adjusted where possible to shift effect from “mission ending” to “degraded mission”
  - Test program accumulating significant mission specific test time
  - Constant drive to identify and strengthen “weak links” to mission success

Reliability Process Overview

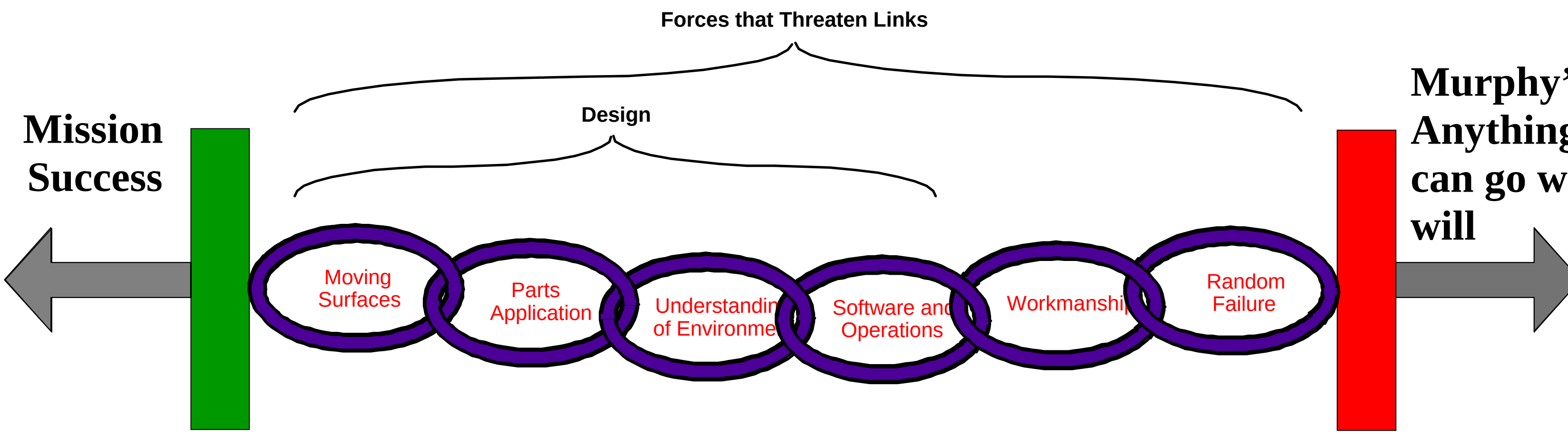
- Reliability is designed in from the beginning
- FMEA to identify mission threatening failures from mission degradation
- Reliability failure rate analysis used to weigh the benefit of one design implementation versus another
- Revise designs to convert loss of mission failures into loss of function or mission degradation
- Inspection to verify as built hardware meets designer’s intent
- Testing to verify as built hardware meets designer’s requirements
- Onboard Fault Detection and Correction to safe spacecaft to provide ground time to react and potentially recover from anomaly
- Operational Contingency Procedures and Backup Plans for mission critical and recoverable failures
- Reliability Philosophy communicated to MAP Hardware Suppliers

Identify Weak Links

Flight Operations Review

Mission Success

Murphy's Law: Anything that can go wrong, will



Mitigators

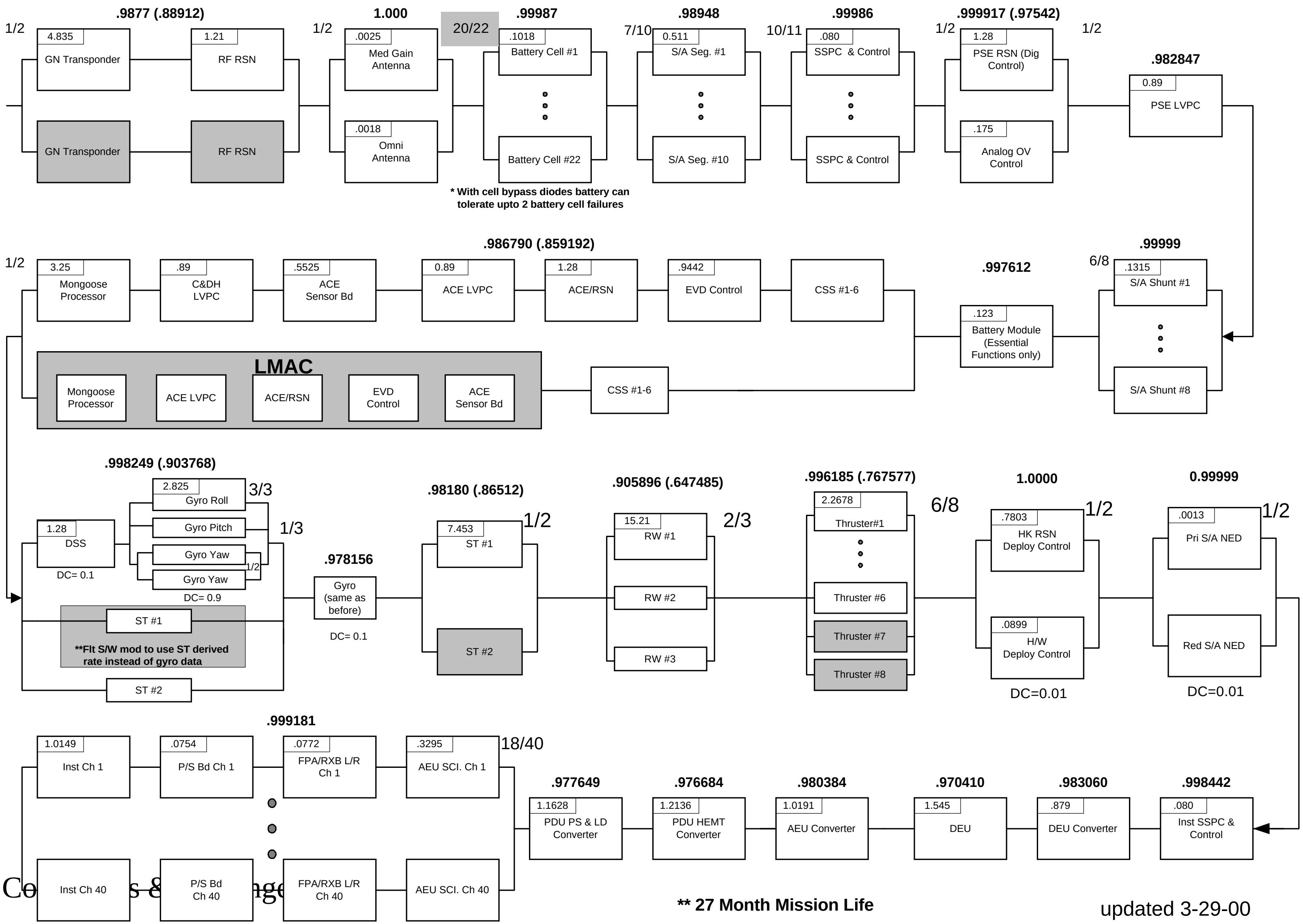
Moving Surfaces	Parts Application	Understanding of Environment	Software and Operations	Workmanship	Random Failure
Design Margin, Redundancy	Parts Stress Analysis to PPL21	Analysis with Single Common Environmental Spec	Integrated Software and Operational Plan	Inspection to NHB5300 or Equivalent, Material and Process Control	Good Parts, Simplicity, Robust Design with Graceful Degradation, Redundancy
Peer Review	Peer Review	Peer Review	Peer Review		
Test	Test	Test	Test	Test	Test

Where is the weakest link?
What will cause a link to break?
Will the "System" hold with a broken link?

M. Bay

MAP Reliability Block Diagram

Flight Operations Review



**** 27 Month Mission Life**

updated 3-29-00

Graceful Degradation & Redundancy

- Baselined Operational Workarounds and Graceful degradation

Prime Item	Mitigator
• Deployment Actuators	2 Deployment Actuators, Double Hinge Bearings & Springs
• Deployment Electronics (HRSN)	Functional Redundancy with LMAC and SADEB
• Gyro Z axis	Overlapping Z Axis
• Gyros	DSS or Star Tracker for X and Y rates
• Wheels	2 of 3 Wheels for Safehold and Degraded Science Mode
• Thruster	Full Redundancy
• Hardware/Software	Safehold (Independent Processor, simple algorithm, reduced ACS hardware set)
• Attitude Control Elec	Full Redundancy
• Transponder	Full Redundancy
• C&DH and Recorder	Full Redundancy
• 1773 Bus and couplers	Inherent Redundancy with standard bus system
• Power System Electronics	Hardware voltage limit with analog backup control
• Battery Cells	Survivable loss of battery cells and Common Pressure Vessels
• Heaters	Survival Heaters backup Operational Heaters
• Instrument	Multiple detector / amplifier channels, multiple linear regulators

- Areas Without Backups
  - Instrument Electronics Power Supply DC/DC Converter and Digital Electronics Unit
  - Power System Electronics Power Supply DC/DC Converter

Reliability Process

Test Phase

1. Test and or execute the sequences planned for the mission. Perform steps and send commands in the expected sequence with the expected timing
2. Command sequences are verified prior to first time execution onorbit. If a sequence is performed onorbit for the first time, analysis should exist that indicates the item will work. Items are tested in “pieces or in steps” instead of relying on analysis alone.
3. Critically test flight and ground software against requirements and the intended end item function.
4. Exercise the hardware and software together during environmental test in the modes they are operated during the mission.

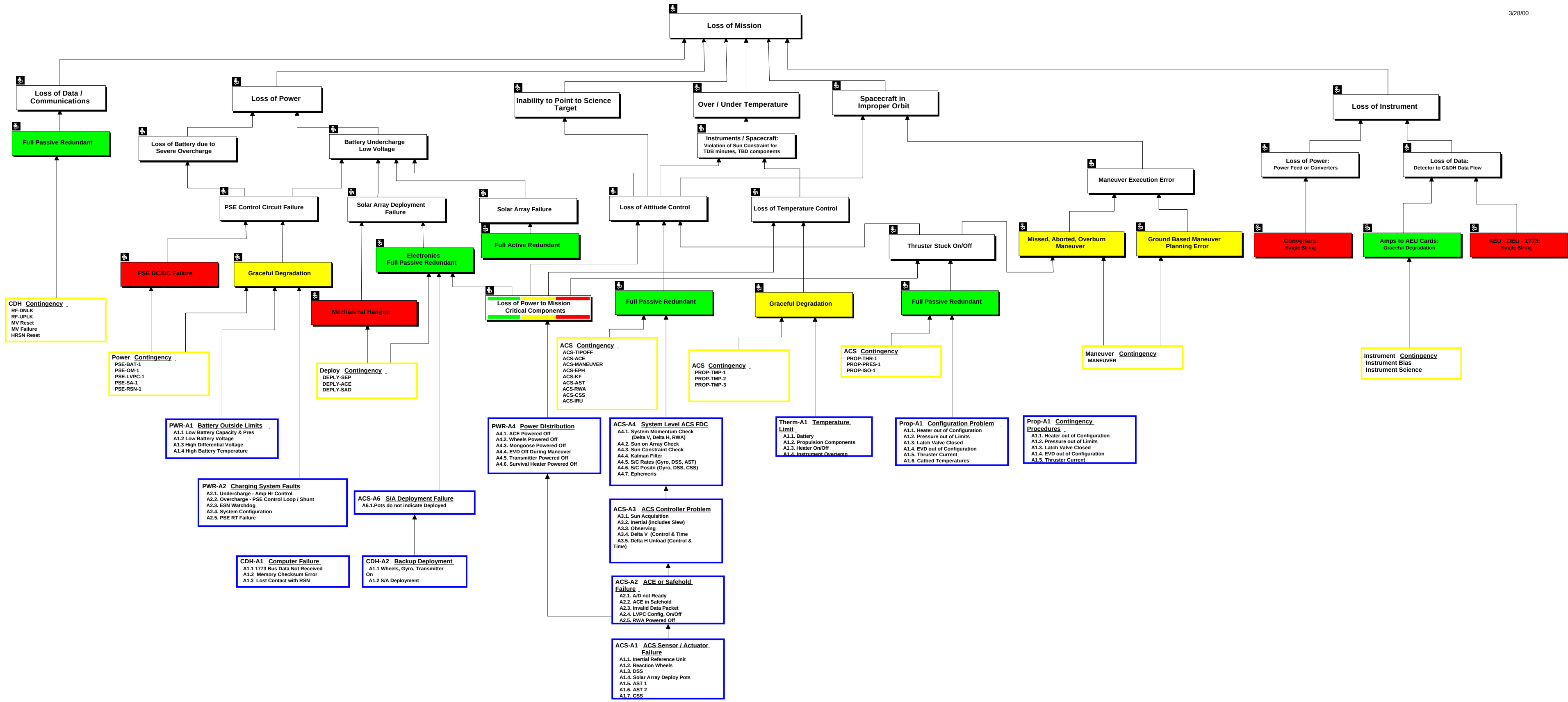
Reliability Process

Operations Phase

1. Utilize a simple subset of the total Spacecraft electronics suite to provide an ACS Safehold that allows additional time for the ground to recover from an anomaly
2. Onboard failure detection to minimize the impact of mission threatening anomalies
3. Contingency procedures prepared for critical subsystems and mission events
4. Training and exercising of the flight and ground systems during prelaunch mission simulations

Mission Fault Tree

Flight Operations Review



Autonomy Approach

Autonomy Philosophy

- Allow the spacecraft to operate safely between ground contacts and/or intervention.
- Allow a reduced and simplified Mission Operation Team and Operations Approach
- Spacecraft can safe itself in the event of an anomaly. The spacecraft attempts to survive a fault until the next ground contact. Implemented via TSM and/or dedicated software
- Applies to attitude and orbit maneuver sequencing. Implemented via stored command processing.

Autonomy Approach

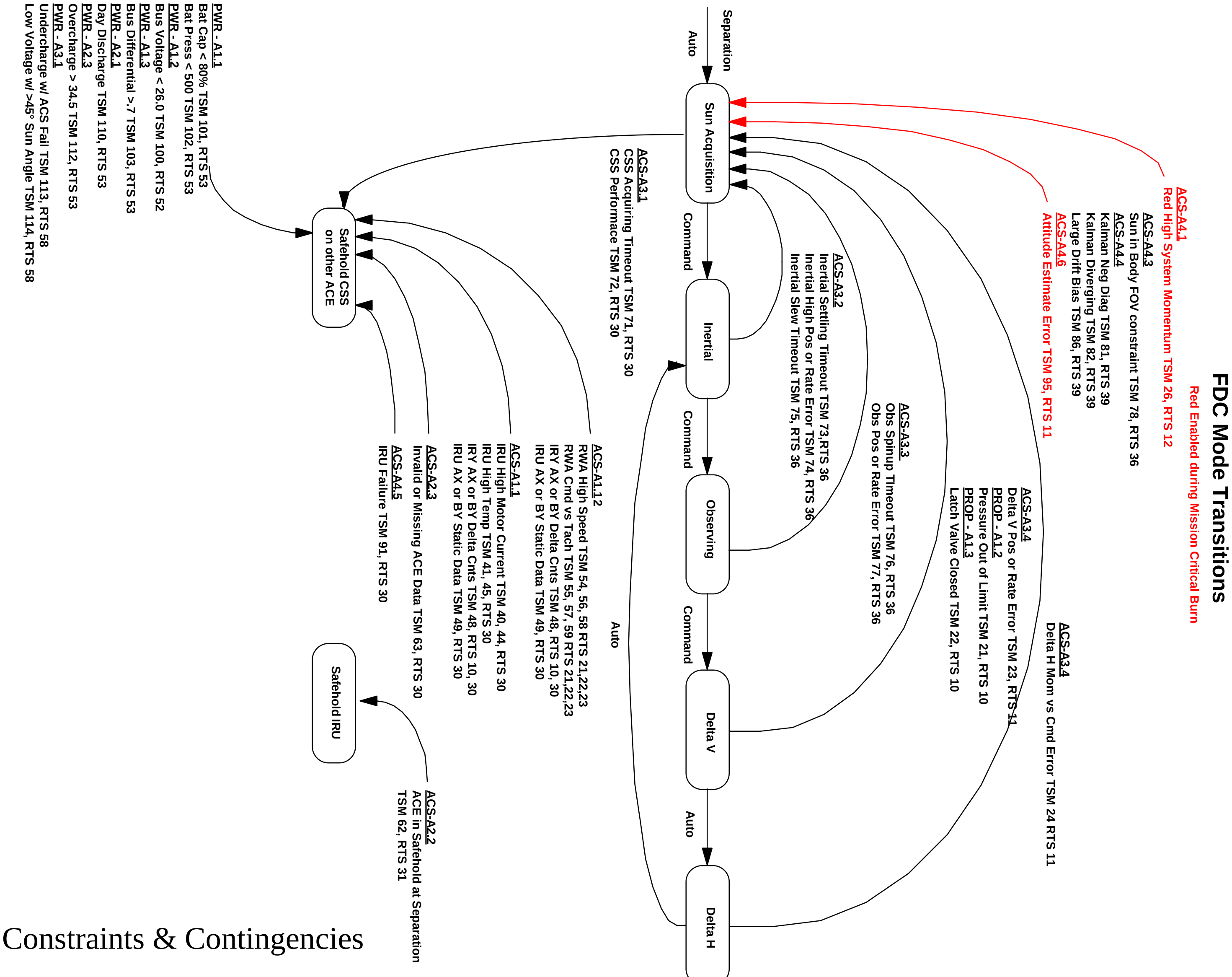
- Simplify ground operations by reducing the ground requirement to react quickly to unexpected situations. Onboard Health and Safety Monitors for power positive and attitude stable on the sunline. Ground still needs to react but with less urgency. Areas where potential loss of mission are mitigated by autonomy:
  - Loss of power (power subsystem or attitude induced)
  - Loss of attitude control
  - Component over or under temperature
  - Spacecraft in Improper Orbit
- Reduce ground workload by tracking and summarizing key health and safety telemetry parameters when limits are exceeded. Reduce requirement to quickly analyze data recorder dumps. Spacecraft can identify where key subsystem parameters maybe out of expected range. Implemented via statistics monitoring TSM.
- Proper onboard execution of the final Perigee Maneuver is critical to achieving proper lunar gravity assist transfer orbit.

Autonomy Approach Capabilities

- Generic TSM, Telemetry and Statistics Monitor
- Generic RTS, Relative Time Sequences
- Unique FDC S/W for Attitude Control
- Selected redundancy is available
- RSNs provide local and simple monitoring for critical functions
- Telemetry provides sufficient sampling for critical items
- Event Messages form a “Log” for quick assessment by the ground. 24 hour Recorder Dump need not be reviewed for quick look assessment.

ACS Autonomous Mode Changes

Flight Operations Review



Implementation and Verification

- Onboard Autonomy Requirements Documented in “MAP Health and Safety Monitoring Requirements MAP-MSN-SPEC-SUB-158, Mongoose Build 2.3 August 18, 1999”
- Document defines TSM and RTS requirements and exact implementation
- TSMs and RTSs part of Flight Software Load
- TSMs and RTSs final update planned prior to Observatory Environmental Test
- Each TSM and RTS requires a successful test and signoff by the subsystem owner prior to flight
- Test are planned on the Observatory, in Flatsat or part of the Mission Simulation Schedule

Operational Constraints

Constraints Document

- For each spacecraft subsystem, special concerns (if any) are discussed. The constraints, restrictions and warnings for each subsystem are presented in tabular form.
  - Constraint is an operation which, if performed, could result in physical stress, damage, or harm to spacecraft flight hardware or result in permanent mission degradation.
  - Restriction is an operation which, if performed, could result in temporary or permanent data loss or abnormal operation but does not stress or damage Fight Hardware.
  - Warning is an explanation of some aspect of the spacecraft system which may not operate as expected or may operate different from what some may interpret as logical.
- A section describing spacecraft mission operational constraints such as solar FOVs and maximum rates of motion is provided.
  - Solar Field Of View Constraints
  - MAP Hot And Cold Solar Orientation
  - RF Communication Subsystem Fields Of View
  - ACS Component Fields of View

Constraints Document cont

- A section describing important spacecraft operational procedures is provided.
  - Reaction Wheel Power On/Off
  - ACE Power On/Off
  - Return To ACS Control From ACE Safehold
  - MAP Instrument Power On/Off
- A section describing potentially hazardous spacecraft commands is provided. These hazardous commands are referenced to the relevant constraint or restriction tabulated earlier for each spacecraft subsystem.
- A listing of "red" and "yellow" limits for telemetry is provided for each spacecraft subsystem.
  - Red limits are the widest temperatures seen by the flight hardware during its test and qualification program. These shall not be exceed in flight.
  - Yellow limits are the flight allowable temperatures

Constraints Document

- Sources of Observatory Constraints
  - Constraints are collected from each subsystem based on their design
  - Problem Failure Reports that identify items that do not function as expected
  - Waivers and Deviations that identify items that do not function as expected
- Document Status
  - MAP Observatory Constraints Manual, MAP–MSN–SPEC–SUB-992, January 18, 2000
  - Baseline Document Complete
  - Update prior to Environmental Test

Contingencies

Contingencies

- Philosophy
  - Develop contingency procedures for mission threatening failures
  - Consider a single failure
  - Ground involvement and required reaction
  - Augment Onboard Autonomous Action for total Mission Safety
  - Procedures tested prior to launch
    - Testing during Thermal Vacuum, End to End Tests, or Mission Simulations
    - Test with actual flight spacecraft if possible
    - Test with Flatsat and Hybrid Dynamic Simulator where necessary

Contingencies Development

- Process
  - Identify Mission Threatening Conditions - Complete
  - Determine if Spacecraft can take some kind of action to mitigate consequence, Separate Onboard versus Ground Actions - Complete
  - Determine if and when the ground can take action - In work
  - Develop Flow Charts - In work
  - Develop Procedure - Complete by Start of S/C Thermal Vacuum Testing
  - Test and Verify procedure on Flatsat or S/C - Planned to start at Thermal Vac
  - Place under configuration management - Launch Minus 3 Months

Contingencies Planning

- Contingency Procedures Required for Mission threat Mitigation
  - Loss of Communication
    - Downlink - Alternate Configurations, LMAC, Transponder , XRSN
    - Command Ability - Transponder, XRSN
  - Solar Array Deployment
    - All panels not deployed - Ground Command Deployment, LMAC, “Shaking”
  - Aborted Maneuver
    - Ground Abort up to Burn Start
      - Table load Error, Configuration Error, Ground not ready
    - Spacecraft Abort after Burn Start - Immediate or delayed Burn Restart
      - High Momentum, High Controller Position or Rate Error, Burn too Long
  - Failed Component
    - Configure to redundant Component
      - Antenna, Receiver/XRSN, LMAC MV, LMAC ACE, Gyro Z, AST for Gyro
  - Develop S/W
    - 2 of 3 Wheel algorithm for a failed wheel

Contingencies Planning cont

- Contingency Procedures Required for Mission threat Mitigation
  - Instrument
    - Over temperature during maneuver / sun impingement - Turn Off
    - React to anomalous drain current and or
  - Computer Cold Start
    - All RSN and MV Reset and Cold Start - Recover last configuration
  - X Axis Delta V Thruster Failure
    - 2 Thruster Configurations
    - Z Axis Configurations
  - Loss of Power
    - Battery Over / Under Charge - Adjust Battery Charge currents, V/T Levels, C/D Ratios
  - Safehold
    - Entrance to Safehold - Assure safe attitudes, switch components as required
    - Exit from Safehold - Assure safe attitudes, switch components as required

Contingencies Planning cont

- Launch Site Contingencies
  - Ground System / Umbilical at KSC
  - Fairing Air Conditioning
  - GN_2 Purge Outage
  - Battery Temperature Rising
  - Launch Recycle
  - Storm, Lightning Alert
  - Emergency Power Off
- Ground System Contingencies
  - Primary Spacecraft Controller Workstation
  - Network / Communications between Facilities
  - FEDS Outage
  - NAVGSE Outage

RF-Comm. Contingency List

Requires Testing (prior to Launch)	ID	Subsystem / Contingency	Action	Flow Chart Status	STOL Procedure Status	Test Status
		RF-Communications				
Yes	RF-DNLK-1	Loss of Dnlk (main)	Command Configuration, Employ Redundancy			
Yes	RF-DNLK-GND-1	-Ground		Under Development	Under Development	Planned End-to-End
Yes	RF-DNLK-SC-1	-RF (mission)	XMTR On-Spec-Cmd,Cmd Omni, Command to Redundant Transponder	Under Development	Under Development: M2CXMTRPWR (75%) M2SXDLSEL(75%)	Partial CPT #1, Full planned CPT #3
Yes	RF-DNLK-SC-2	-RF (L&IOC)	XMTR On-Spec-Cmd,Cmd Omni, Command to Redundant Transponder	Under Development	Under Development: M2CXMTRPWR(75%) M2SXDLSEL(75%) M2CXRSNBOMNI(90%)	Partial CPT #1, Full planned CPT #3
Yes	RF-DNLK-SC-3	-RF (First TDRS and GDS Pass)				
Yes	RF-DNLK-MV-1	-No Data (good RF)	Config XRSN, Re-Boot MV from PROM, Command to Redundant MV	Under Development	Under Development: M2CMVPROMBOOT (50%) M2CMVSWITCH (75%)	Partial CPT #1
Yes	RF-UPLK-1	Loss of Uplk (main)				
Yes	RF-UPLK-GND-1	-Ground		Under Development	Under Development	Planned End-to-End
Yes	RF-UPLK-SC-1	-Spacecraft	Cmd other XRSN, Command redundant MV	Under Development	Under Development: M2SXUPLSEL (75%)	Partial CPT #1, Full planned CPT #3
Yes		Transponder Failure	Command to Redundant Transponder	Handled in Loss of Comm	Handled in Loss of Comm	

C&DH and Deployment Contingency Lists

Requires Testing (prior to Launch)	ID	Subsystem / Contingency	Action	Flow Chart Status	STOL Procedure Status	Test Status
		C&DH				
		Mongoose V μP reset recovery		N/A	Under Development: M2CMINIT (50%)	
Yes		Mongoose V Failure	Command to Redundant MV	Handled in Loss of Comm	Handled in Loss of Comm	
		HKRSN μP Cold Reset recovery		N/A	Under Development: M2CHINITVER (25%)	
		Solar Array Deployment				
Yes	DEPLOY-SEP-1	-Arrays did not deploy	-Manual Deploy via HKRSN	Complete	M2CEMANUALDEPLOY (75%)	CPT #1
Yes	DEPLOY-ACE-1	-Arrays did not deploy	-Manual Deploy via ACE	Complete	M2CEMANUALDEPLOY (75%)	CPT #1
Yes	DEPLOY-SAD-1	-Arrays not fully deployed	Shake S/C via wheels, thrusters			

ACS Contingency List

Flight Operations Review

Requires Testing (prior to Launch)	ID	Subsystem / Contingency	Action	Flow Chart Status	STOL Procedure Status	Test Status
		ACS				
Yes		Identify Stable Sunsafe Attitude	Command Alternate Configuraton			
Yes	ACS-TIPOFF-1	High Tip-Off Rates (main)	Command Momentum Unload	Under Development		
Yes	ACS-TIPOFF-2	- ACS ΔH (>2σ rates)	Goto ACS DeltaH mode	Under Development	Complete (draft): M2SADELTAH (90%)	Partial w/ FlatSat Mission Sim #2
Yes	ACS-TIPOFF-3	- Manual (ground) ΔH (ACE in Sfhld)	Manually command thrusters via ACE cmd	Under Development		
Yes	ACS-ACE-1	No ACE data (launch)	Failover LMAC ACE		Complete (draft): M2CALMACACEPWR (75%)	
Yes		ACE Failure	Command Redundant ACE			
Yes	ACS-MAN-1	Maneuver (main) (for ongoing S/C maneuver)				
Yes	ACS-MAN-2	-Maneuver did not start				
Yes	ACS-MAN-3	-Maneuver did not stop				
Yes	ACS-MAN-4	-Maneuver Aborted				

ACS Contingency List (cont.)

Requires Testing (prior to Launch)	ID	Subsystem / Contingency	Action	Flow Chart Status	STOL Procedure Status	Test Status
		ACS				
	ACS-EPH-1	Bad Ephemeris				
	ACS-EPH-2	Stale Ephemeris				
	ACS-KF-1	Kalman Filter diverged				
	ACS-KF-2	Kalman Filter not updating				
	ACS-AST-1	AST Failure				
Yes	ACS-RWA-1	Wheel Failure			M2SAGOTOSH	Two Wheel Control patch written & tested by FSW test team
Yes	ACS-RWA-2	Wheel Polarity				
Yes	ACS-CSS-1	CSS Failure				
Yes	ACS-IRU-1	IRU Failure	Command Redundant IRU, Config DSS as rate source			
Yes		Safehold Recovery	Sfhld. -> Sun Acq -> Inertial -> Observing Mode	N/A	M2SAEXITSH	Tested w/ FlatSat during Mission Sim #2
Yes		ACE μP Cold Reset recovery		N/A		

Maneuver Planning and Propulsion Contingency Lists

Requires Testing (prior to Launch)	ID	Subsystem / Contingency	Action	Flow Chart Status	STOL Procedure Status	Test Status
		Maneuver Planning				
Yes	MANEUVER-1	Maneuver Planning Overall Flow (inc. Cal, Perigee, Apogee, L2)		Under Development		Partial w/ FlatSat Mission Sim #2
		Maneuver during station contacts				
Yes		Thruster Failure (planning)				
Yes		Missing all prigee burns				
Yes		Split perigee maneuvers				
Yes		LV injection orbit error $>3\sigma$				
		Propulsion				
Yes	PROP-THR-1	Thruster Failure (S/C)	Select Alternate Thruster			
Yes	PROP-THR-2	Thruster Polarity	Change Direction Matrix			
Yes	PROP-TMP-1	Valve Temperature		Under Development		
Yes	PROP-TMP-2	Tank/Line Temperature	Readjust Electronic Thermostat	Under Development		
Yes	PROP-PRES-1	Pressure Transducer	Utilize Backup Fuel Accounting	Under Development		
Yes	PROP-ISO-1	Isolation Valve Closed	Open Isol Valve	Under Development		
	PROP-TMP-3	Heater Cycling	Readjust Electronic Thermostat	Under Development		

PSE, Instrument and Thermal Contingency Lists

Flight Operations Review

Requires Testing (prior to Launch)	ID	Subsystem / Contingency	Action	Flow Chart Status	STOL Procedure Status	Test Status
		PSE				
Yes		Identify Power Positive State	Command Configuration & Try Alternates			
	PSE-BAT-1	Battery Monitoring		Complete	Under Development	
Yes	PSE-OM-1	SSPC Monitoring	Activate All On Special Command	Complete	Complete	CPT #1
	PSE-LVPC-1	LVPC Monitoring		Complete	Complete	CPT #1
	PSE-SA-1	Solar Array Monitoring		Complete		
Yes	PSE-RSN-1	RSN Failure	Activate Analog Backup on S/A Module	Complete		
	PSE-SHUNT-1	Loss of Shunt Control (ie. Inability to regulate Load Bus via SA shunting)	Use Solar Array offset to sunline to regulate Array input to battery/load bus			
Yes		PSE RSN μP Cold Reset recovery		N/A	Complete: M2CPLCONFIG	
		Instrument				
		Drain Current reaches a red high limit.	Command DA off	Under development	Under development	
		Recovery from power-off (safing recovery)		Under development	Under development	
		Thermal				
		Temperatures out of Range	Command Heater Configurations			

Launch-Site Contingency List

Requires Testing (prior to Launch)	ID	Subsystem / Contingency	Action	Flow Chart Status	STOL Procedure Status	Test Status
		Launch-Site (PAD)				
		Ground System (Including: GSE/ Umbilical/ Network)				
		Fairing Air Conditioning				
		GN_2 Purge Outage				
Yes		Battery Temperature Rising				
Yes		Launch Recycle				
Yes		Storm, Lightning Alert				
Yes		Emergency Power Off				

Contingencies

- Contingency / Anomaly Recovery Plan
  – Identification of an problem triggers an Problem Failure Report
  – A contingency procedure is initiated
  – Appropriate Systems and Subsystems personnel are contacted
  – Observatory Health and Safety is restored / established
  – Anomaly review is held to decide on next course of action and ultimate return to normal operation
  – Plan to return to normal operation requires, Subsystem, System, Spacecraft Controller Team, Science Team, and Mission Operations Manager Signoff
  – Problem Failure Report report is closed out after normal operations is restored

Mission Readiness Testing

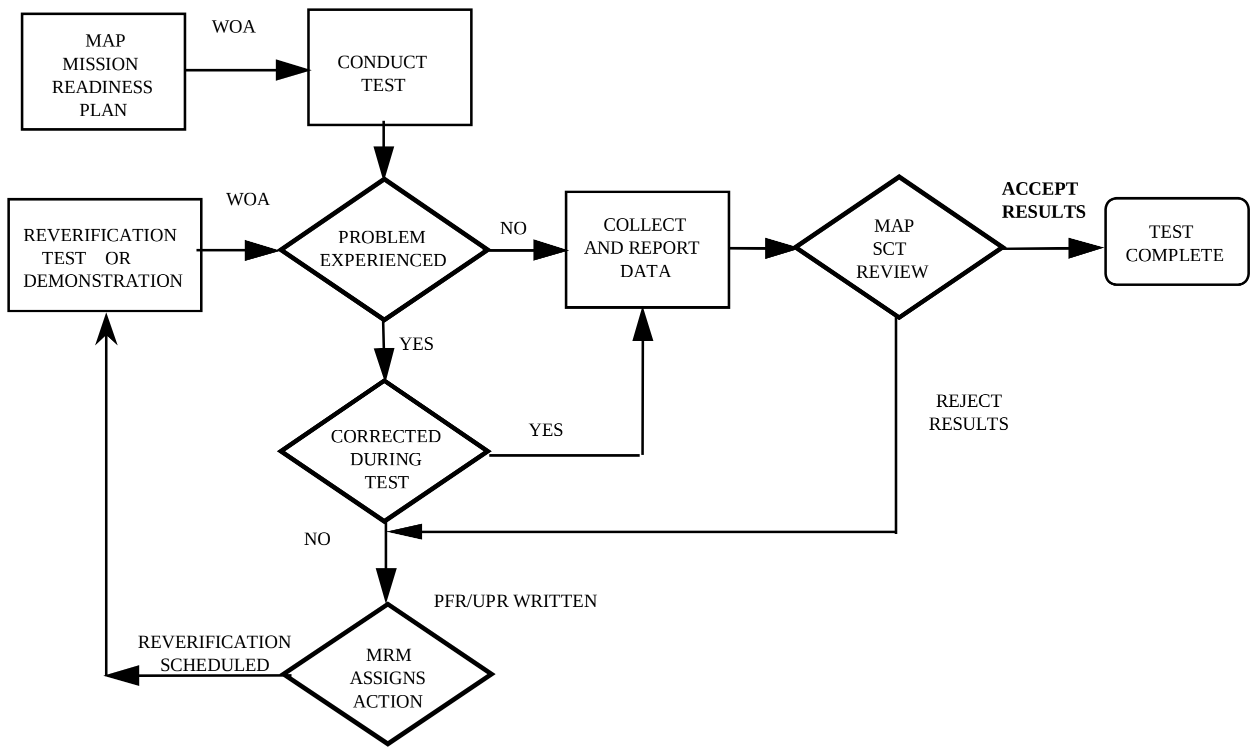
Kevin Blahut

MRT Process

- Ground System requirements are documented in:
  - Medium Class Explorer (MIDEX) Microwave Anisotropy Probe (MAP) Combined Ground System (CGS) Requirements (map-grnd-spec-sub-153)
  - Detailed Mission Requirements (DMR) for the Microwave Anisotropy Probe (MAP) - Signature Copy (June 1999)
- Tests are defined according to the Combined Ground System Integration and Test Plan (map-moda-intg-sub-149)

MAP Mission Readiness Test Execution Process

Flight Operations Review



Test Phases

- Test Phases (all Complete)
  - Ground System Release Acceptance Testing (GSAT), all releases of the Ground System receive 30 days of Acceptance Testing before use in Ground System Verification Testing.
  - Ground System Verification Testing (GSVT), All Operational Data Bases (ODBs) and Ground System Releases successfully tested during GSAT and are verification tested before being used in tests with the flight system. GSVT is used for verification of all Ground System Level 2 Requirements as documented in the MAP Detailed Mission Requirements.
  - RF Compat Tests performed with the flight transponers: The CTT and MIL-71 used for DSN compatibility testing. The RFSOC used for SN compatibility testing
  - SMOC Compatibility tests are functional tests performed Between SMOC and FlatSat or the Spacecraft

Test Phases

- Test Phases (cont)
  - Mission Simulations:
    Used to validate all elements of MAP system: Observatory, DSN, NISN, SMOC, Science Data Processing in a realtime operational environment. Launch simulations start with Pre-Launch Countdown, Launch, IOC and maneuver activities and end with nominal Science data processing

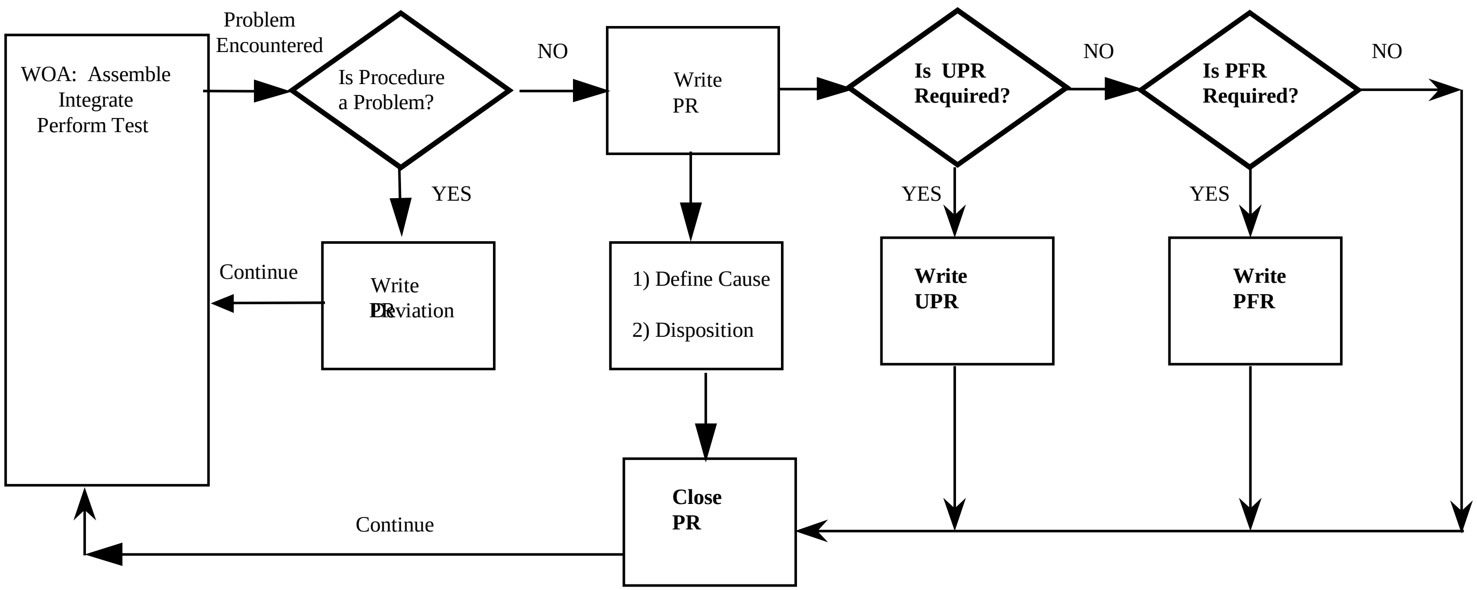
MRT Objectives

- Ensure the Combined Ground System can support all mission requirements.
- Verify the integrated capability of the Combined Ground System in an end-to-end configuration.
- Provide a documented record of Combined Ground System performance, test discrepancies, and resolution.

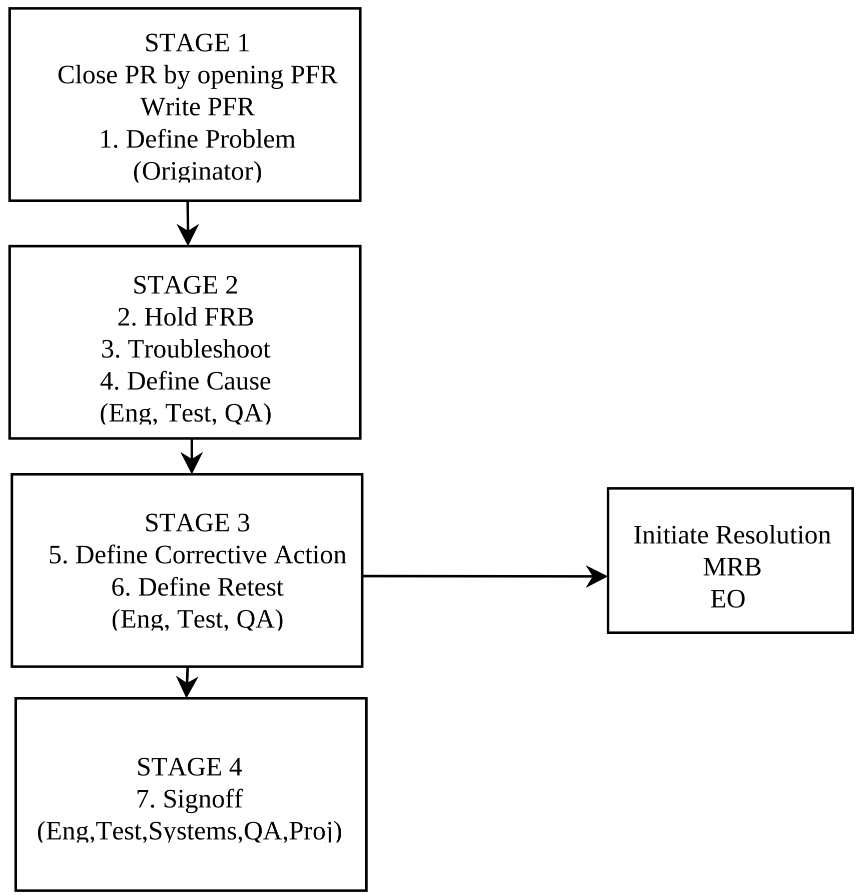
WOA Process Flow

Flight Operations Review

The Project WOA system is utilized to document and authorize Mission Readiness Tests

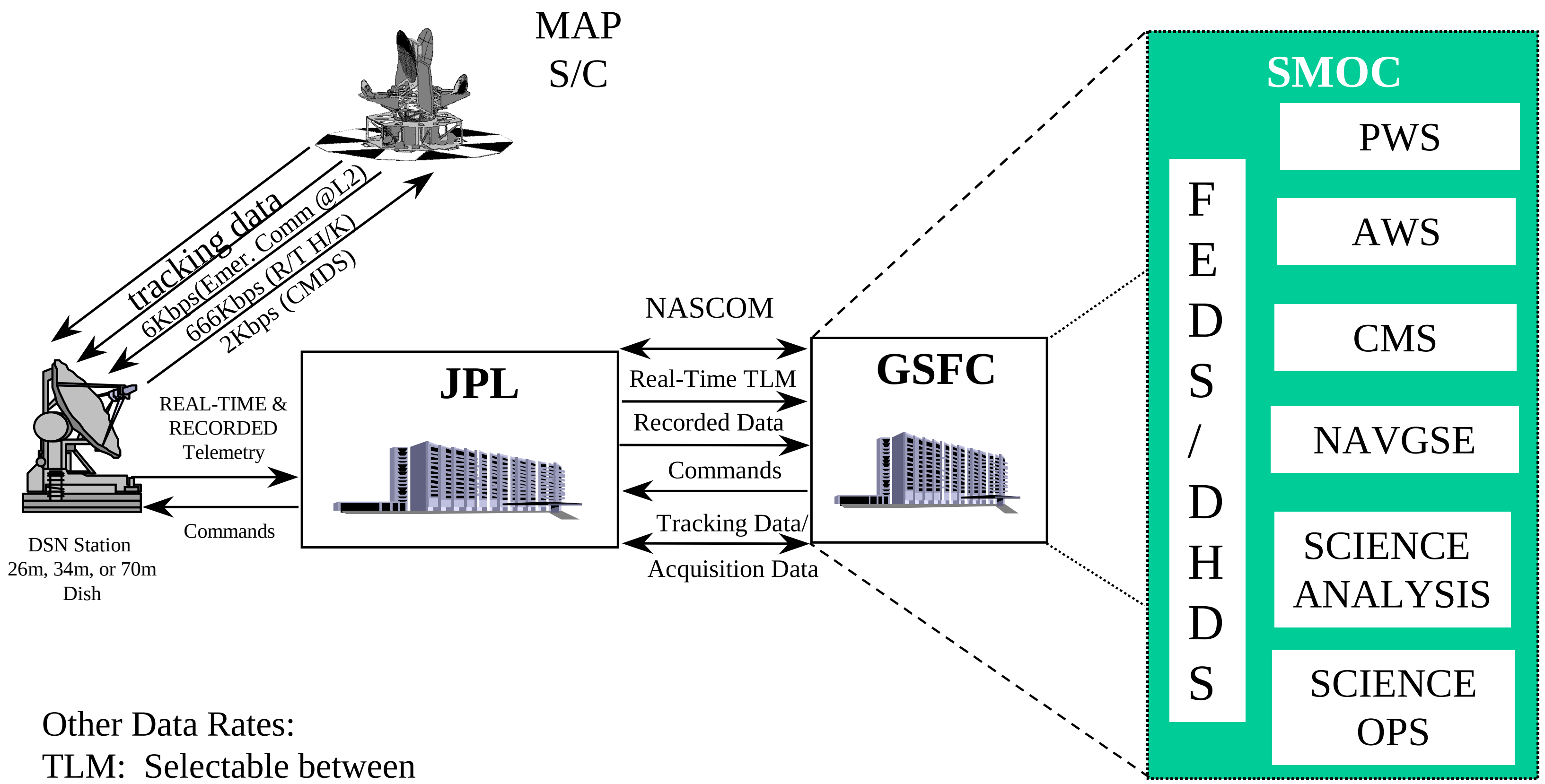


PFR Reporting



MAP Data Flow Diagram

Flight Operations Review



Other Data Rates:
TLM: Selectable between
2Kbps, 100Kbps, 120Kbps,
222Kbps, or 1Mbps

Mission Readiness Testing to date

- 5 Canned data flows with commanding from DTF-21
- End-to-End data flow through the CTT/JPL
  - TDRSS telemetry tests through the RFSOC
- Mission Sim #1 SMOC Compat with S/C
  - Normal L2 Operations from the SMOC
  - TDRSS telemetry tests through the RFSOC
- Mission Sim #2 Launch and IOC (22-25 Feb, 2000)
  - Launch with the S/C
  - IOC with FlatSat
  - Perigee Maneuver
  - Normal L2 Operations and Data Processing

Mission Simulation Schedule

Flight Operations Review

<u>Mission Simulation #2</u>
2/22/00
- Nominal
- Launch
- IOC
- Maneuver

<u>FLATSAT</u>
2/23-25/00
- Maneuver
- Ground System
- End-to-End

<u>Mission Simulation #3</u>
4/00
Flatsat
- Aborted Burn
- Cal Burn
- ACS Contingency

<u>Mission Simulation #4</u>
5/00
Spacecraft
- Launch
- Deploy w/ Contingency
- Power Contingency

Flatsat
- All Cal Burns
- Maneuver w/ Contingency

<u>FLATSAT</u>
- Maneuver
- ACS Contingency

<u>Mission Simulation #5</u>
Thermal Vac
Spacecraft
- Launch
- Deploy
- Contingency
  - RF
  - C&DH

<u>FLATSAT</u>
- IOC/Cal Burns
- Maneuver

<u>Mission Simulation #6</u>
Pre-Ship
Spacecraft
- Launch
- Contingency
  - RF
  - Power

Flatsat
- Maneuver Proficiency & Contingency

<u>Mission Simulation #7</u>
Post-Ship
Spacecraft
- Launch
- Deploy
- Contingency

Flatsat
- Maneuver Proficiency & Contingency

<u>Mission Simulation #8</u>
Pre-Stacking
Spacecraft
- Launch

Flatsat
- Maneuver Proficiency & Contingency

<u>Rehearsal</u>

Paper & Voice

<u>Demonstration</u>
T-6
Spacecraft
- Launch
- Contingency

Mission Simulation Schedule Summary

- 13 Mission and Launch Simulations Planned
  - Mission Sims performed utilizing the strengths of both S/C and FlatSat. Most Sims hand over from S/C to FlatSat after Sep
    - 8 Sims on the S/C
    - 9 Sims on FlatSat
  - 2 At the Eastern Range + Mission Rehearsal with the Range
- All Simulations in Realistic Launch and IOC Environment
- "No Joy" Paper Sims Begin L-3 Month

Test Verification Matrix

Flight Operations Review

Test Category	Total	Passed	Failed	To Be Tested	%Passed	%Failed	% To be Tested
ASIST/FEDS	228	224	0	4	98%	0%	2%
AUTO OPS	21	5	10	6	24%	48%	29%
Facilities	6	6	0	0	100%	0%	0%
Launch Support	2	0	0	2	0%	0%	100%
FD/FDF	41	9	0	32	22%	0%	78%
DSN/SN	49	43	0	6	88%	0%	12%
CMS/Mission Planning	112	102	10	0	91%	9%	0%
DPS/ Sci Interface	12	11	0	1	92%	0%	8%
MRT	27	21	0	6	78%	0%	22%
CGS Hardware	9	9	0	0	100%	0%	0%
GSE	2	2	0	0	100%	0%	0%
TOTAL	509	430	20	57	84%	4%	11%

*ASIST/FEDS includes R/T command and control, trending, database management and display capabilities

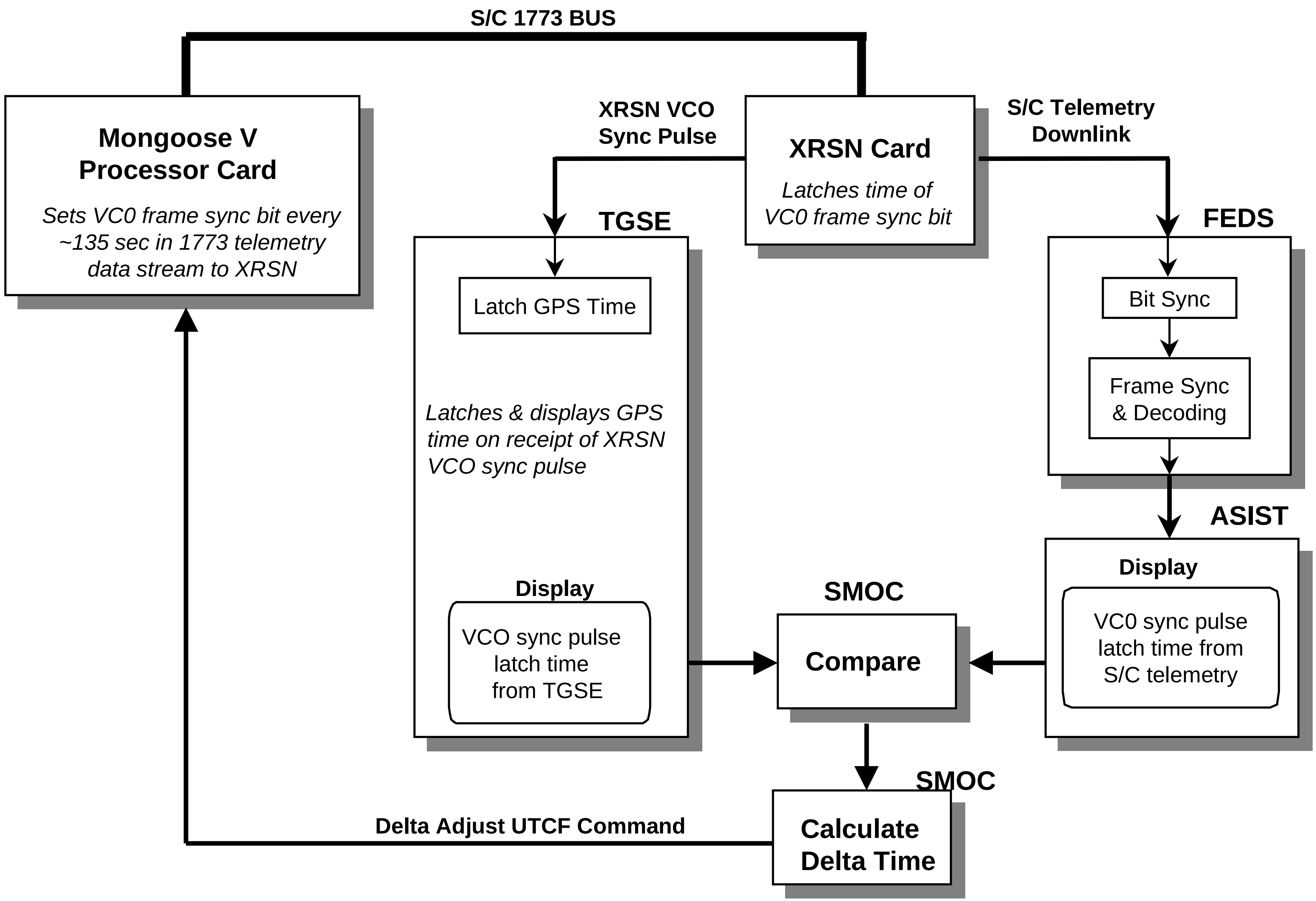
*AUTO OPS includes requirements to enable automating operations

Box Runtime

COMPONENT	hhhh:mm	COMPONENT	hhhh:mm
PSE	1233:13	CATBEDS 5&6	0:39
MAC	1131:00	CATBEDS 7&8	0:41
XPNDR A (RCV)	1025:05	DSS	98:38
XMITTER A	65:14	ISO-VALVE	73:45
XPNDR B (RCV)	1022:52	TARA1	160:05
XMITTER B	13:43	TARA2	152:42
XPNDR HTR	0:41	LVPC11	0:48
ST1	42:34	5V	0:39
ST2	29:40	-15V	0:39
CATBEDS 1&2	0:40	15V	0:39
CATBEDS 3&4	0:39	LVPC15	839:57

As of March 8,1999

MAP Spacecraft Time Verification



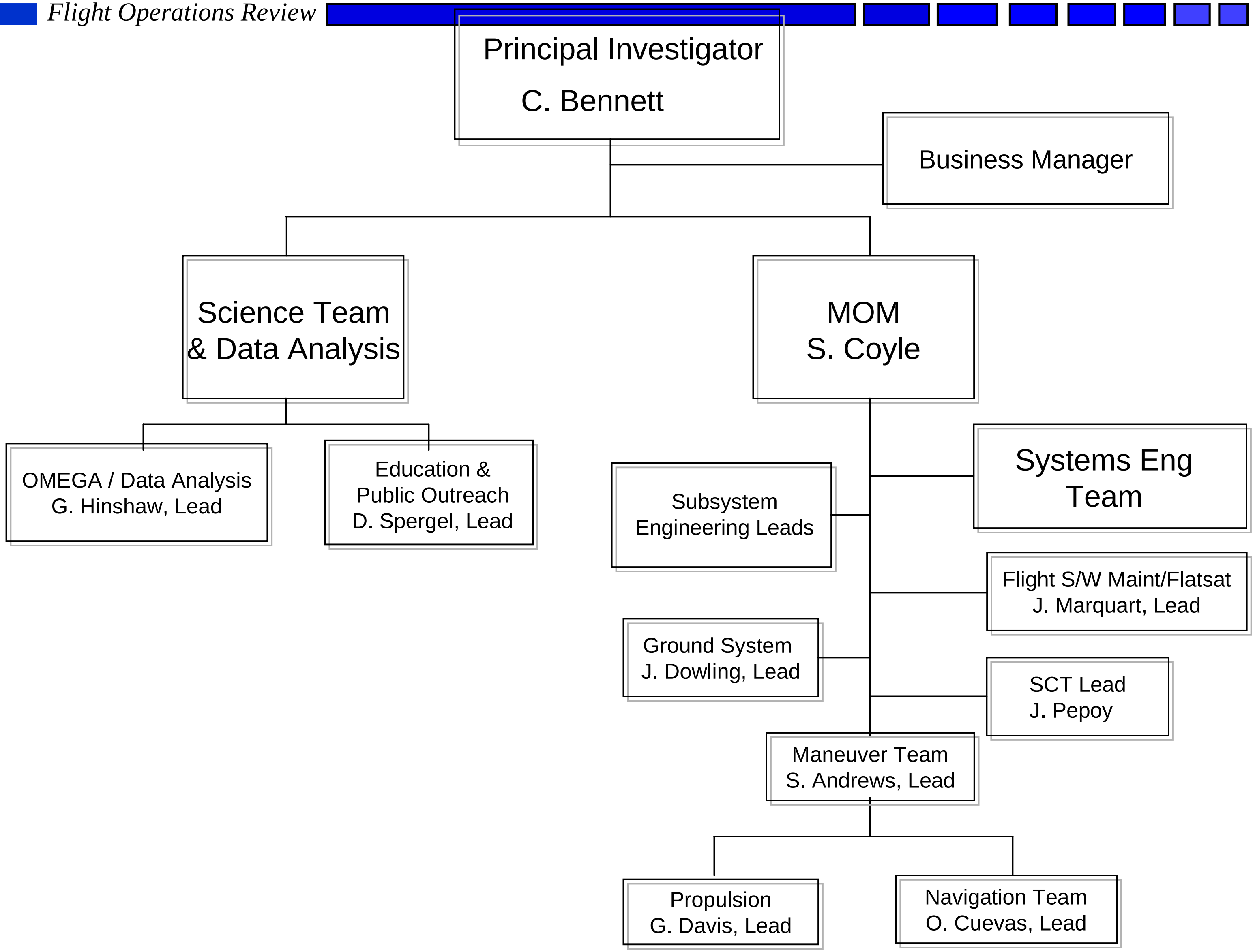
On-Orbit
Management Approach

Steven Coyle

Management Transition

- Through IOC, defined as a successful arrival at L2
  - The existing MAP Project Organization Chart remains in place
  - Roles and Responsibilities remain in place
  - CM system remains in place
- After arrival at L2, the MO&DA Organization Structure will assume responsibility

MO&DA Organization Chart



Roles and Responsibilities

- **Principal Investigator** (Chuck Bennett) - Overall responsible for the execution of the MAP mission. Co-chair of the on-orbit CCB.
- **Science Team** (Gary Hinshaw) - Responsible for all instrument operations, science data analysis and CMB map generation
- **Mission Operations Manager** - Responsible for the overall operations of the MAP observatory, which includes health and safety. Manage the SCT. Co-chair of the on-orbit CCB.
- **Spacecraft Controller Team** - Responsible for all aspects and duties associated with mission operations.

Roles and Responsibilities

- **Maneuver Team** - Responsible for the design and maintenance of the MAP trajectory through all mission phases.
- **Subsystem Engineers** - Responsible for their given subsystem until successful in-orbit checkout. Available, as needed, for consultation in the event of any anomaly. Periodically, evaluate subsystem performance based on trend reports generated by the SCT.
- **Systems Engineers** - Responsible for the overall observatory performance. Coordinate subsystem support during IOC. Available, as needed, for consultation in the event of any anomaly. Periodically, evaluate subsystem performance based on trend reports generated by the SCT.

Roles and Responsibilities

- **Flight Software Maintenance Team -** Responsible for the on-orbit operation of the flight software. Correct any discrepancies in the flight code. Modify the flight code to maintain optimum observatory performance.
- **Ground System Development Team -** Responsible for maintaining the ground system software. Modify the ground system code based on discrepancies and enhancements needed by the SCT

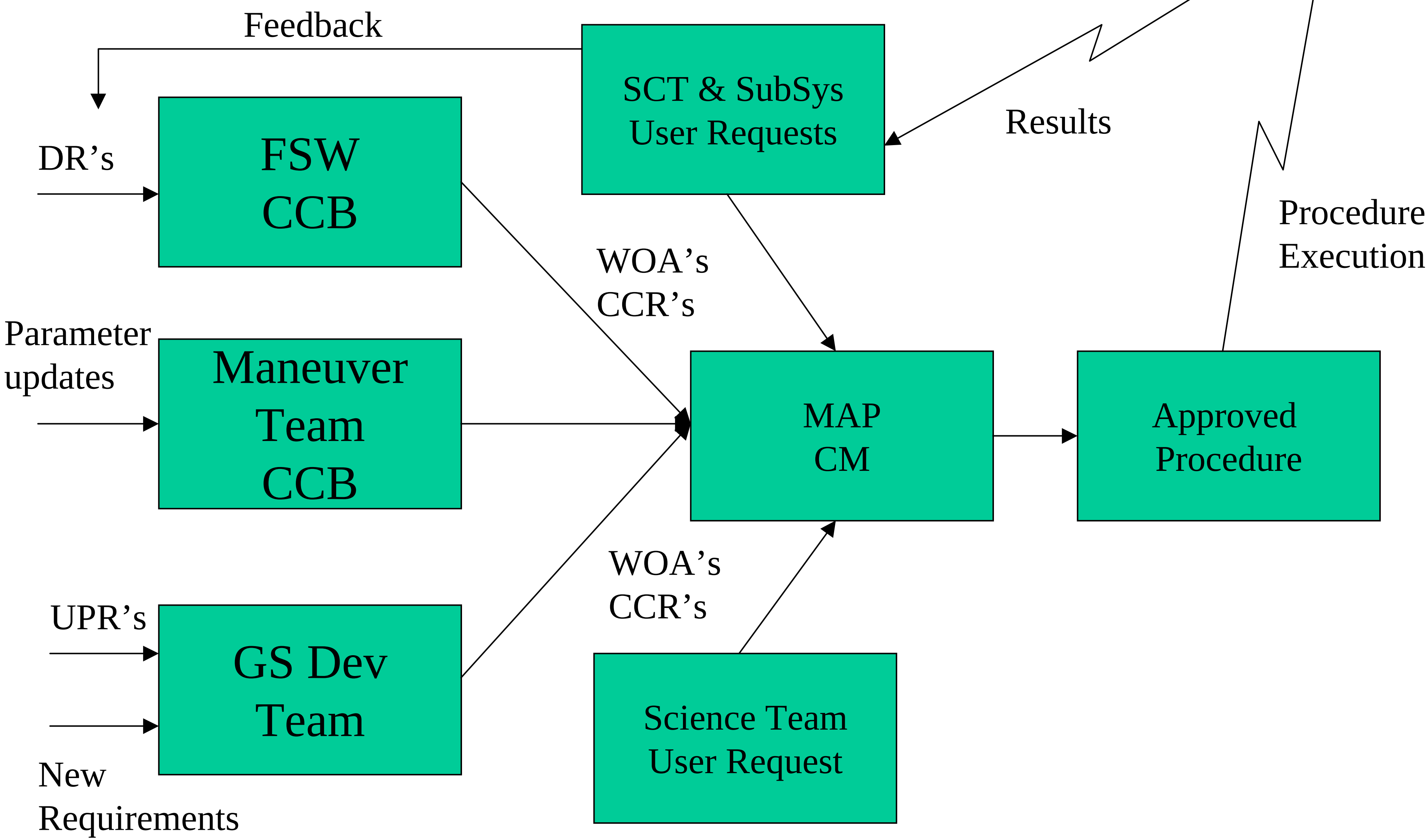
Configuration Management

- The MAP Project, network based, CM system will transition to the SMOC after launch. The on-orbit CM process will be identical with the existing project process. The signature authority will be modified to reflect the on-orbit support staff.
  - At launch, the database will be configured and signed off. This includes:
    - Telemetry and Command RDL’s
      - Calibration curves
      - Limits
    - STOL Procedures
    - Pages
  - All Ops Doc’s will be completed and signed

Configuration Management

- Any updates or modifications needed to the configured database or the signed ops docs will require a CCR
- All activities executed on the spacecraft will require a WOA
  - Weekly Pass plan
  - Maneuvers
  - special ops: FSW patches, table edits
- Signature flow: Originator => SCT Lead => MOM => PI
- All support CCB's will flow into the MAP CM system
  - FSW
  - Maneuver Team
  - Ground System Development Team

CM Flow


Feedback
SCT & SubSys User Requests
Results
DR's
FSW CCB
Procedure Execution
WOA's CCR's
Parameter updates
Maneuver Team CCB
MAP CM
Approved Procedure
WOA's CCR's
UPR's
GS Dev Team
New Requirements
Science Team User Request

Launch and IOC Management

Steven Coyle

Launch Commit Criteria

- **Spacecraft**
  - Successful Pad functional test
  - Observatory is in launch configuration and state-of-health verified through telemetry
  - No red or unexplainable yellow limits
  - Launch team must confirm nominal spacecraft performance
- **Instrument**
  - Successful Pad functional test
    - The instrument is not powered at launch

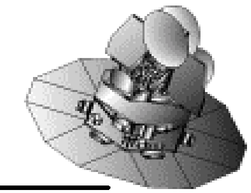
Launch Commit Criteria

- **Ground System**
  - **SMOC** or MITOC (GSFC)
    - Must be able to process telemetry and execute commands to maintain the observatory in a safe operational mode
  - **SAEF-2**
    - Must be able to process telemetry and execute commands to maintain the observatory in a safe operational mode
  - **MMFD** (FDF)
    - Must be prepared to preprocess DSN tracking data and deliver the data to the SMOC
  - **Deep Space Network**
    - Goldstone must report in “Green” with at least one station operational and pre-calibrated to support MAP

Launch Commit Criteria

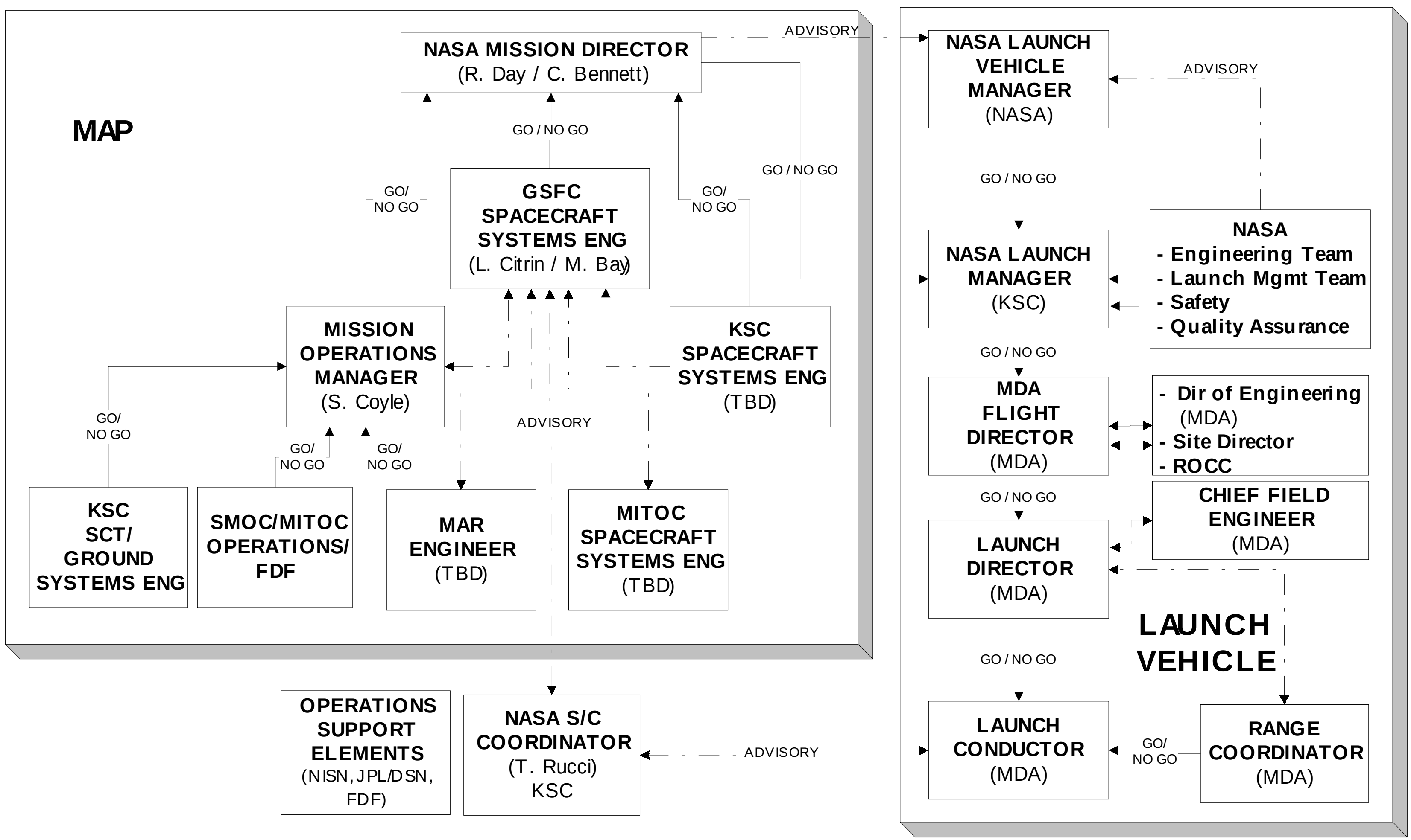
- **Ground System (cont.)**
  - **TDRSS**
    - Configured to provide telemetry and command support during spacecraft separation from the launch vehicle
  - **NASCOM**
    - All voice and data circuits must be fully operational between the SMOC or MITOC, SEAF-2 and the DSN

Launch Management
Launch Decision Flow



NASA LAUNCH DAY MANAGEMENT

GO / NO GO =
ADVISORY =



IOC Process

- IOC Work Process
  - All IOC activities and timelines will be documented in the MAP IOC Plan.
    - The IOC plan will be encrypted into a series of modular STOL procedures. This procs will be tested, signed and configured in the operational database.
    - The chronological execution of the of the procs will be documented in the IOC plan

IOC Process

- Minor deviations to the IOC Plan
  - Deviations, which do not introduce risk to the mission, will be handled in realtime utilizing Command Request Forms. The Command Request Form will include the following information:
    - What command/procedure needs to be sent
    - When the command/procedure needs to be sent
    - Justification of why the command/procedure needs to be sent
    - Signatures: Originator=>SS lead=>Systems=>MOM
      - The Command Controller will initial and enter time of execution on both the form and in the console log

IOC Process

- Anomalies
  - When an anomalous condition has been recognizes Systems will direct the operations team to execute the appropriate contingency procedure.
  - Once the spacecraft is safe, Systems will muster an anomaly investigation team. The team will:
    - Investigate the Anomaly
    - Document the Anomaly as a PFR
    - Generate an plan of action
      - The Plan of Action must be signed by: all Subsystems=> Systems=> MOM=> PM=> PI
    - Encrypt the plan of action into a STOL procedure
      - Test the procedure on FlatSat, when appropriate
    - Execute the Procedure

Systems & Subsystems Staffing/Mission Phase

Subsystem Staffing Overview:

Mission Day	Pre-Launch L-5 L+0	IOC L+0			L+34	Cruise L+35 L+90	L2 Ops L+91	EOL
		IOC Ops L+0 L+7	Manuever Ops Perigee Coincidence	Nominal Pass Ops L+7 L+34	Special Ops - Mid-Course Correction	Nominal Pass Ops L+35 L+90	Normal Routine Operations with Automation Tested	Delta-V Operations
SMOC	- Primary Control Site - SCT 24 hours/day - System Support All Pad Testing - Subsystem Support All Pad Testing - Maneuver Team Day Shift off-line analysis	- Primary Control Site - SCT 24 hours/day - System Support 24/day - Subsystem Support ASC/FSW/Prop 24/day Others: 12/day - Maneuver Team 24/day off-line analysis	- Primary Control Site - SCT 24 hours/day - System Support 24/day - Subsystem Support ASC/FSW/Prop 24/day Others: 12/day - Maneuver Team 24/day off-line analysis	- Primary Control Site - SCT 24 hours/day - System Support 12/day - Subsystem Support ASC/FSW Day/Swing Shift Others: Day Shift - Maneuver Team Day/Swing Shift off-line analysis	- Primary Control Site - SCT 24 hours/day - System Support 12/day - Subsystem Support ASC/FSW/Prop 12/day Others: as needed - Maneuver Team 12/day off-line analysis	- Primary Control Site - SCT Day/Swing Shift - System Support as needed - Subsystem Support as needed - Maneuver Team Day Shift off-line analysis	- Primary Control Site - SCT Day Shift - System Support as needed - Subsystem Support as needed - Maneuver Team One Day/Week off-line analysis	- Primary Control Site - SCT 2 Shifts - System Support as needed - Subsystem Support ASC/FSW/Prop 12/day - Maneuver Team 12/day off-line analysis
MITOC	- 3rd Backup Control - 4 Instr Controllers & Science Team All Pad Testing - GS Developers Day Shift	- 3rd Backup Control - 4 Instr Controllers & Science Team 24/day - GS Developers Day Shift	- 3rd Backup Control - 4 Instr Controllers & Science Team 12/day - GS Developers Day Shift	- 3rd Backup Control - 4 Instr Controllers & Science Team Day Shift - GS Developers Day Shift	- Backup Control Site - Available if needed			
CAPE	- 3rd Backup Control - SCT 24/Day - Management & Systems All Pad Testing							
Auto-mation	None	None	None	Shadow mode	None	Shadow mode transitioning to active mode for routine ops	Active mode	None

Science and Mission Operations Center Facilities

Steven Coyle

MAP SMOC

Flight Operations Review

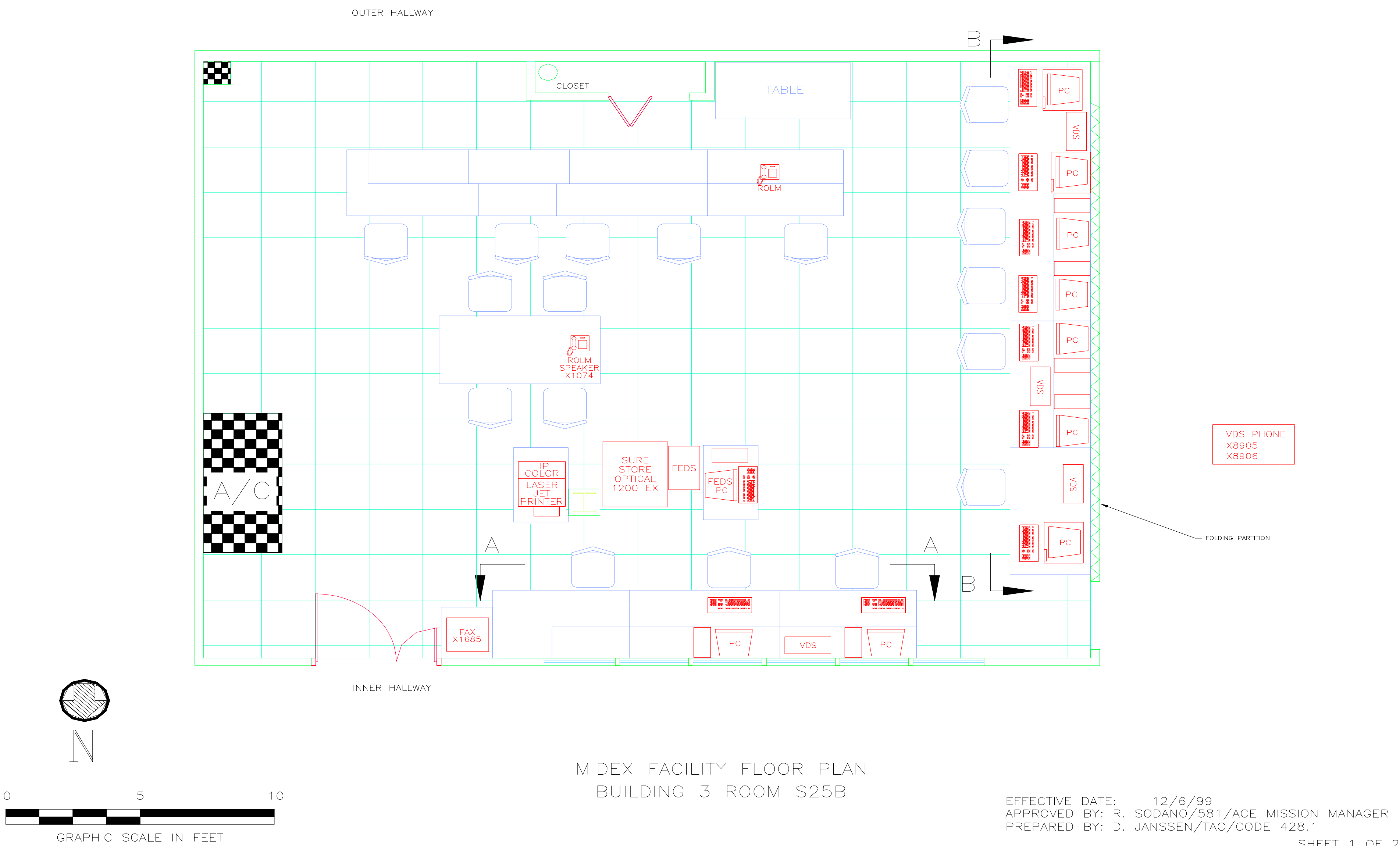
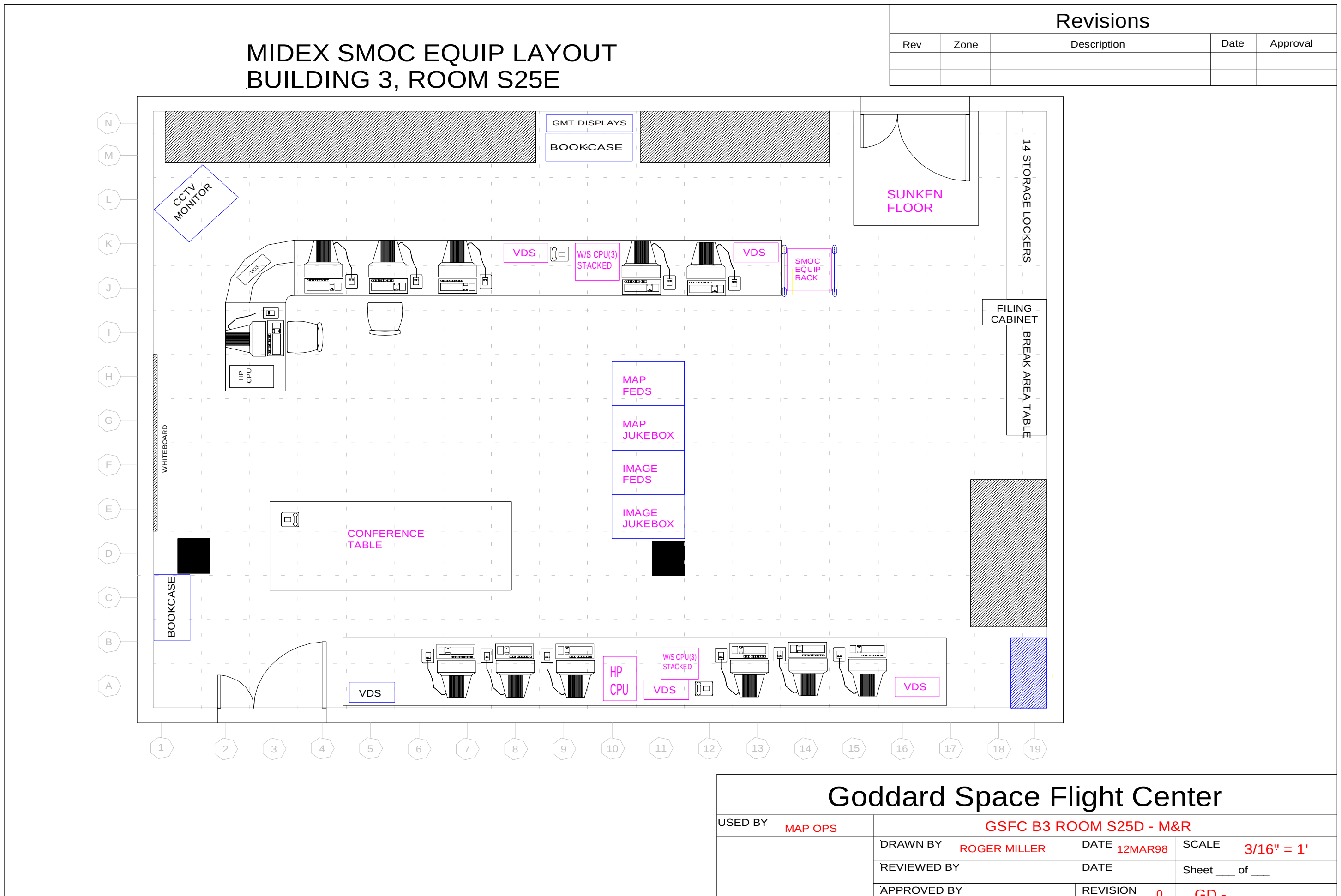


IMAGE SMOC

Flight Operations Review

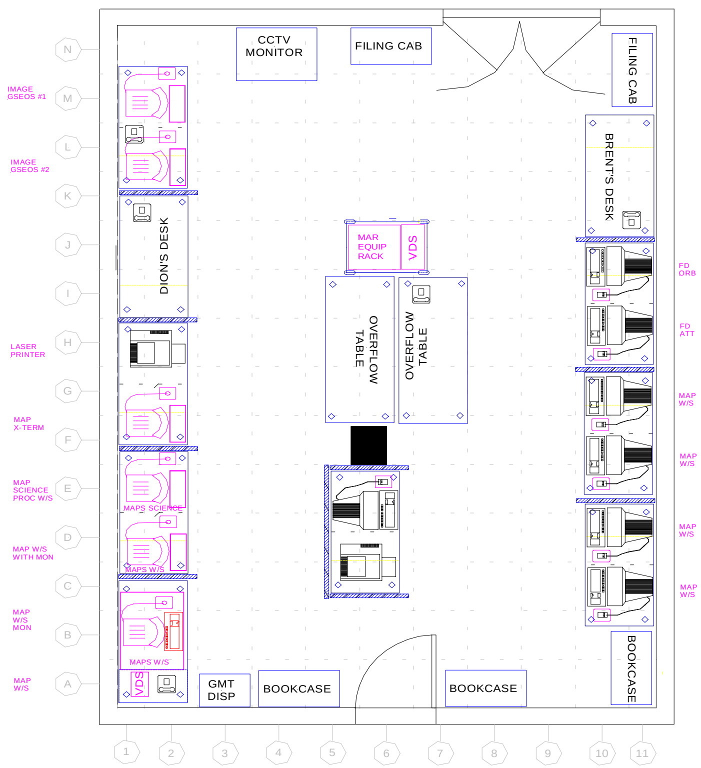


MAP/IMAGE MAR

Flight Operations Review

MIDEX NETWORK LAYOUT
BUILDING 3, ROOM S25D

Revisions				
Rev	Zone	Description	Date	Approval



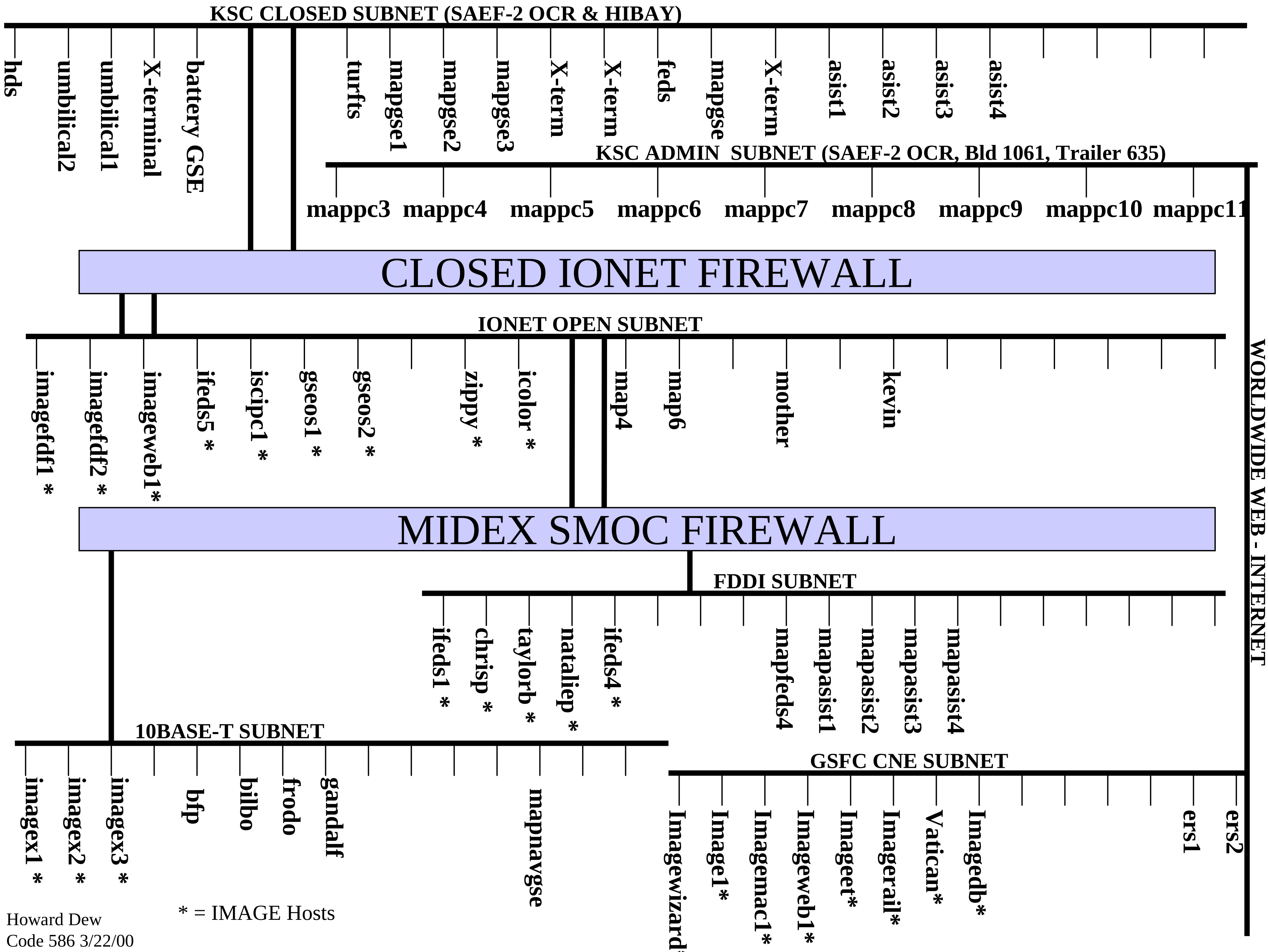
Goddard Space Flight Center

USED BY MAP OPS	GSFC B3 ROOM S25D - M&R		
	DRAWN BY ROGER MILLER	DATE 12MAR98	SCALE 1/8" = 1'
	REVIEWED BY	DATE	Sheet ___ of ___
	APPROVED BY	REVISION 0	GD -

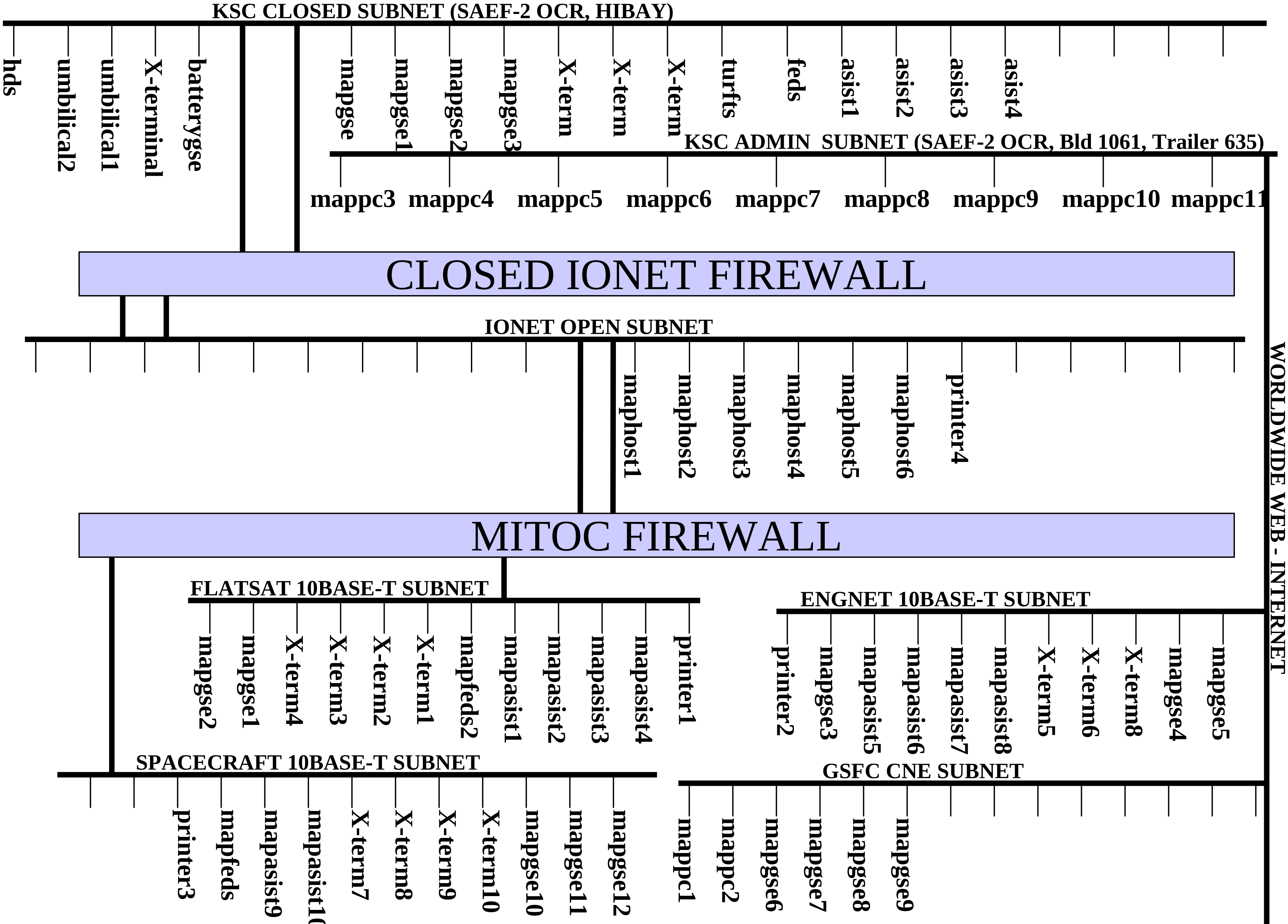
Position	Launch Coord	Delta Coord	Launch Status	S/C Coord	Launch I&T	Systems	Engr1	Engr2	MAP Ops Coord	DSN Coord	SN Coord
Loop Name	LAUNCH_CD	DELTA_CD	LAUNCH_ST	S/C_COORD	LAUNCH_IT	S/C_SYSTM	S/C_ENG_1	S/C_ENG_2	OPS_COORD	DSN_COORD	SN_COORD
Loop #	SCAMMA 1	SCAMMA 2	SCAMMA 3	SCAMMA 4	SCAMMA 6	SCAMMA 9	SCAMMA 7	SCAMMA 8	CCL2	SCAMMA 5	CCL1
MAP MGT	Mon	Mon	Mon	T/L	T/L	*	**	**	**	**	
MITOC OPS	Mon	Mon	Mon	Mon**	T/L	*	**	**	T/L	T/L	T/L
MITOC ENG	Mon	Mon	Mon	Mon**	T/L	T/L	**	**	Mon	Mon	*
SMOC OPS	Mon	Mon	Mon	Mon**	T/L	*	**	**	T/L	T/L	T/L
SMOC EGR	Mon	Mon	Mon	Mon**	T/L	T/L	**	**	Mon	Mon	*
MAR OPS	Mon	Mon	Mon	Mon**	T/L	*	**	**	T/L	Mon	Mon
MAR EGR	Mon	Mon	Mon	Mon**	T/L	T/L	**	**	Mon	Mon	*
FDF	Mon	Mon	Mon	Mon**		*	**	**	T/L	Mon	Mon
SAEF-2	Mon	Mon	Mon		T/L	*	**	**	**	**	
ER	T/L	T/L	T/L		T/L						
DSN										T/L	
MIL-71					T/L						
CDR										T/L	
GN										Mon	
NCC										Mon	T/L
NISN					T/L				T/L		
CTT											
MCR	Mon	Mon	Mon	Mon**	Mon**	Mon**	**	**	*	*	*
MDR									*		
ETF					T/L	T/L	**	**	T/L		
PDO						T/L			*		
		* Monitor when requested				** Talk/listen when requested					

Network and Facility Security

Steven Coyle



Howard Dew
Code 586 3/22/00



Howard Dew
Code 586 3/22/00

SMOC/MITOC Physical Security

1. MAP SMOC, Building 3, Room S25B, requires keycard entry to shared mission hallway with IMAGE SMOC.

2. MITOC, Building 29, Room 156, requires keycard entry.

3. NASA-issued badges are required to be visible at all times by personnel working in these areas.

4. Entry to GSFC campus requires NASA-issued badge.

5. Doors to Building 3 and Building 29 are keycard activated for after hours entry.

6. Guards rove GSFC grounds once per hour.

MAP SMOC/MITOC Information Security

1. MAP SMOC hosts protected from IONET OPEN intrusion by MIDEX firewall shared with IMAGE SMOC.

2. IONET CLOSED hosts protected from MAP SMOC hosts by NASCOM gatekeeper firewall and by security measures taken within the SMOC.

3. MITOC hosts protected from IONET OPEN intrusion by MITOC firewall identical to MAP SMOC MIDEX firewall.

4. IONET CLOSED hosts protected from MITOC hosts by NASCOM gatekeeper firewall and by security measures taken within the MITOC.

MAP SMOC/MITOC Information Security

5. MAP SMOC, MITOC and SAEF-2 security personnel shall:

- follow rules of behavior for hosts on IONET CLOSED
- insure that security checklist procedures are followed through enforcement by MAP Security Manager and MAP area Security Officers (MITOC, MAP SMOC, SAEF-2)
- conduct Risk Assessment Plan for each area to determine security vulnerabilities
- create Security Plan outlining all security measures to protect against hardware, software and informational compromises
- implement security procedures to conform to Security Plan

6. MAP Security Manager and Security Officers shall require an internal security scan to further locate individual host vulnerabilities.

7. Personnel training shall be conducted to insure each person's under-standing of the security vulnerabilities and procedures to be taken.

Spacecraft Controller Team

Steven Coyle

SCT Philosophy

- Single Spacecraft Controller Team (SCT)
  - Deployed the SCT into the instrument and component development labs
  - Each Controller assigned as lead on a subsystem
  - Each Controller follows the component through all phases of testing
  - The SCT conducts spacecraft and observatory I&T
    - Integration
    - Environmental Testing
    - Launch site operations
  - The SCT performs all operations preparations
    - End-to-End Testing
    - Mission and Launch Simulations
  - The SCT performs on-orbit operations

Nominal Operations Staffing Overview

Operations Staffing Overview:

Mission Day	Pre-Launch L-5 L+0	IOC L+0			L+34	Cruise L+35 L+90	L2 Ops L+91	EOL
		IOC Ops L+0 L+7	Manuever Ops Perigee Coincidence	Nominal Pass Ops L+7 L+34	Special Ops - Mid-Course Correction	Nominal Pass Ops L+35 L+90	Normal Routine Operations with Automation Tested	Delta-V Operations
SMOC	- Primary Control Site - Staffed 24 hours/day - 2 Controllers per shift - 1 Controller: Day shift, scheduling, off-line analysis - 2 Controllers: Day/Swing shifts, off-line analysis	- Primary Control Site - Staffed 24 hours/day - 2 Controllers per shift - 1 Controller: Day shift, scheduling, off-line analysis - 2 Controllers: Day/Swing shifts, off-line analysis	- Primary Control Site - Staffed 24 hours/day - 2 Controllers per shift - 1 Controller: Day shift, scheduling, off-line analysis - 2 Controllers: Support special ops	- Primary Control Site - Staffed 24 hours/day - 2 Controllers per shift - 1 Controller: Day shift, scheduling, off-line analysis - 2 Controllers: Day shift, off-line analysis	- Primary Control Site - Staffed 24 hours/day - 2 Controllers per shift - 1 Controller: Day shift, scheduling, off-line analysis - 2 Controllers: Support special ops	- Primary Control Site - Staffed 16 hours/day - 2 Controllers per shift - 1 Controller: Day shift, scheduling - Remaining Controllers: Day shift, off-line analysis, Automation work	- 5 Controllers total - 8 hours per day - Typically Monday-Friday day shift	- 5 Controllers total - 3 Controllers on-console during Delta-V operations - 2 Controllers cover extended DSN coverage period
MITOC	- Backup Control Site - 4 Instr Controllers - SCT maintained	- Backup Control Site - 4 Instr Controllers - SCT maintained	- Backup Control Site - 4 Instr Controllers - SCT maintained	- Backup Control Site - 4 Instr Controllers - SCT maintained	- Backup Control Site - SCT configures but does not staff			
CAPE	- Backup Control Site - 2 Controllers provide all coverage needed							
Auto-mation	None	None	None	Shadow mode	None	Shadow mode transitioning to active mode for routine ops	Active mode	None

Nominal Operations Staffing Overview

- Operations Staffing Overview

- Launch: L-5 days to L+0

- SMOC: 9 Controllers Total
  - >> 2 Controllers per shift, 8 hours per shift, 24 hours per day (6)
  - >> 1 Controller - scheduling, off-line analysis (1)
  - >> 2 Controllers - off-line analysis (2)

- MITOC: 4 Instrument Controllers Total
  - >> SCT maintains MITOC, but does not provide full-time staff

- CAPE: 2 Controllers Total
  - >> Ops coverage as needed (2)

Nominal Operations Staffing Overview

- Operations Staffing Overview

  - **IOC/Phasing Loops**: L+0 to L+34 days

    - SMOC: 11 Controllers Total
      - >> 2 Controllers per shift, 8 hours per shift, 24 hours day (8)
      - >> 1 Controller - scheduling, off-line analysis (1)
      - >> 2 Controllers - anomaly team, maneuver team (2)

    - MITOC: 4 Instrument Controllers Total
      - >> MITOC configured as a backup control center
      - >> SCT & ground system team maintain MITOC

Nominal Operations Staffing Overview

- Operations Staffing Overview

  - **Cruise**: L+35 days to L+90 days

    - SMOC: 11 Controllers Total

      >> 2 Controllers per shift, 8 hours per shift, 16 hours per day (6)

      >> 1 Controller - scheduling, off-line analysis (1)

      >> 2 Controllers - off-line analysis, test auto-ops in shadow mode (4)

    - MITOC:

      >> Decommissioned

      >> Available if needed

Nominal Operations Staffing Overview

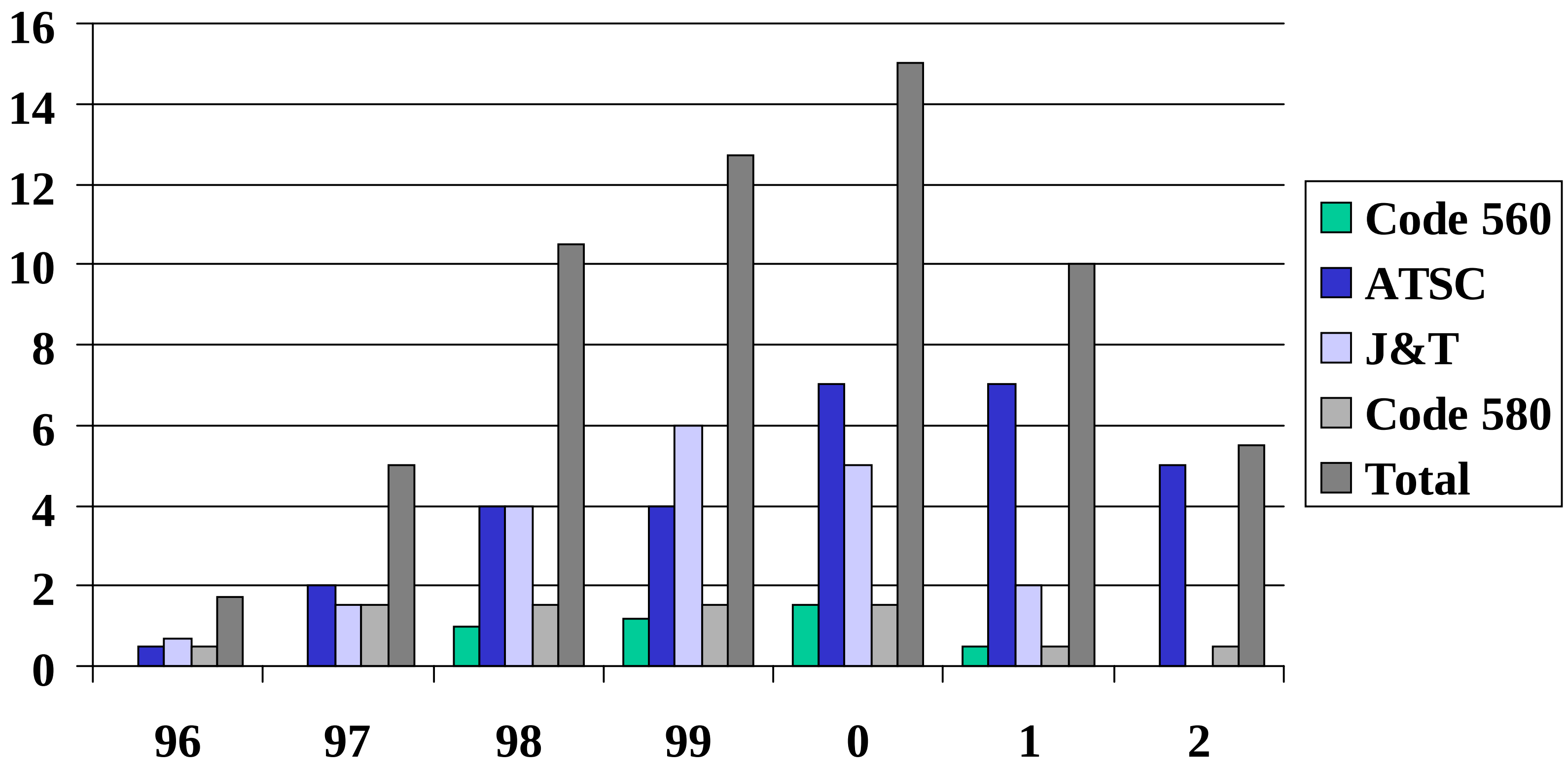
- Operations Staffing Overview

  - L2 Operations: L+91 days to EOL

  - Begin phase-down of SMOC support: 5 Controllers Total
    - >> Nominal ops coverage handled by automation
    - >> Nominal staffing: Monday - Friday, 8 hours per day
    - >> Special ops staffing: 5 Controllers cover Delta-V operations
      - 3 Controllers on-console during Delta-V ops
      - 2 Controllers on-console during extended coverage

SCT Staffing

Flight Operations Review



Nominal Operations Staffing Overview

Flight Operations Review

MAY 2000

DAY	M	T	W	TH	F	SA	S	M	T	W	TH	F	SA	S	M	T	W	TH	F	SA	S	M	T	W	TH	F	SA	S	M	T	W
MAY	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
A1		D	D	D	D	D		D	P1	P1	P1	P1			S	S	S	S	S			P2	P2	P2	P2	P2				D	D
A2		D	D	D	D	D		D	P1	P1	P1	P1			S	S	S	S	S			P2	P2	P2	P2	P2				D	D
B1	S	S	S	S	S			P2	P2	P2	P2	P2				D	D	D	D	D		D	P1	P1	P1	P1			S	S	S
B2	S	S	S	S	S			P2	P2	P2	P2	P2				D	D	D	D	D		D	P1	P1	P1	P1			S	S	S
C1	P2	P2	P2	P2	P2				D	D	D	D	D		D	P1	P1	P1	P1			S	S	S	S	S			P2	P2	P2
C2	P2	P2	P2	P2	P2				D	D	D	D	D		D	P1	P1	P1	P1			S	S	S	S	S			P2	P2	P2
D1	D	P1	P1	P1	P1			S	S	S	S	S			P2	P2	P2	P2	P2				D	D	D	D	D		D	P1	P1
D2	D	P1	P1	P1	P1			S	S	S	S	S			P2	P2	P2	P2	P2				D	D	D	D	D		D	P1	P1

S = Swings (Eves) = M-F 3:00 PM - 11:30 PM
D = Days = Tu - F 7:00 AM - 3:30 PM & Sa 7:00 AM - 7:00 PM

P1 = Prime 1 = M-F 7:00 AM - 3:30 PM
P2 = Prime 2 = M-F 7:00 AM - 3:30 PM

P1 = If required, cover unexpected leading day (up to 12 hours/day)
P2 = If required, cover unexpected leading Nights (12 hrs/night); unepxected nights during weekdays (8 hrs/night)

NOTE: On unexpected weekend coverage, P1/P2 shifts will be 12 hour shifts to cover entire 24 period if required.
\# This indicates scheduled day off AND not available to cover unexpected shift

12 hour day shifts: 7:00 AM - 7:00 PM
12 hour night shifts: 7:00 PM - 7:00 AM

Spacecraft Controller Training

- The SCT and operational ground system support MAP from component development through end of mission life
- Formal training courses for the SCT have been given in ESD Certification and the Ground Segment.
- A Spacecraft Systems course will be developed by the SCT and presented prior to the end of Spacecraft Integration.
- Written tests will be given for formal certification to all new controllers
- Comprehensive training & certification of the SCT will occur during the following tests:
  - Comprehensive Performance Tests
  - End-to-End Tests
  - 13 Mission Simulations
    - 7 Launch Sims
  - As Needed FLATSAT Simulations

Ops Documents Status

DOCUMENT	STATUS	FINAL
• Constraint Plan	DRAFT	L-6 months
• Contingency Plan	REVIEW	L-3 months
• S/C Configuration	near FINAL	L-8 months
• Launch Mgmt Plan	REVIEW	L-6 months
• IOC & L-2 Ops Plan	DRAFT	L-6 months
• LSSP	FINAL inputs in	Complete
• KSC Deployment Plan	CONCEPT	pre ship
• DSN Ops Agreement	DRAFT	L-3 months
• Flight Ops Plan	this review represents BASELINE	

Flight Software Maintenance

Jane Marquart

FSW Maintenance

- GSFC’s Flight Software Branch (582) to provide on-orbit maintenance (through CSC contractor team)
- Flight Software Maintenance will take place in the MAP ETU facility (Building 1)

Maintenance Activities

- **Pre-launch**
  - Move and re-certify testbed
  - Develop Maintenance Plan
  - Develop FOT ICD
  - Support all I&T testing, I.e. CPTs, mission sims
  - Develop regression test suite
  - Verify tools; coordinate with FOT
  - Develop FSW library
- **Post-launch**
  - Investigate FSW anomalies
  - Support recovery from s/c emergencies
  - Develop TSMs and other FSW-controlled tables
  - Develop FSW patches as required
  - Support FOT (inquiries, testbed usage, FSW products)
  - Maintain FSW Testbed
  - Co-chair FSW CCB

Maintenance Facility

Flight Operations Review

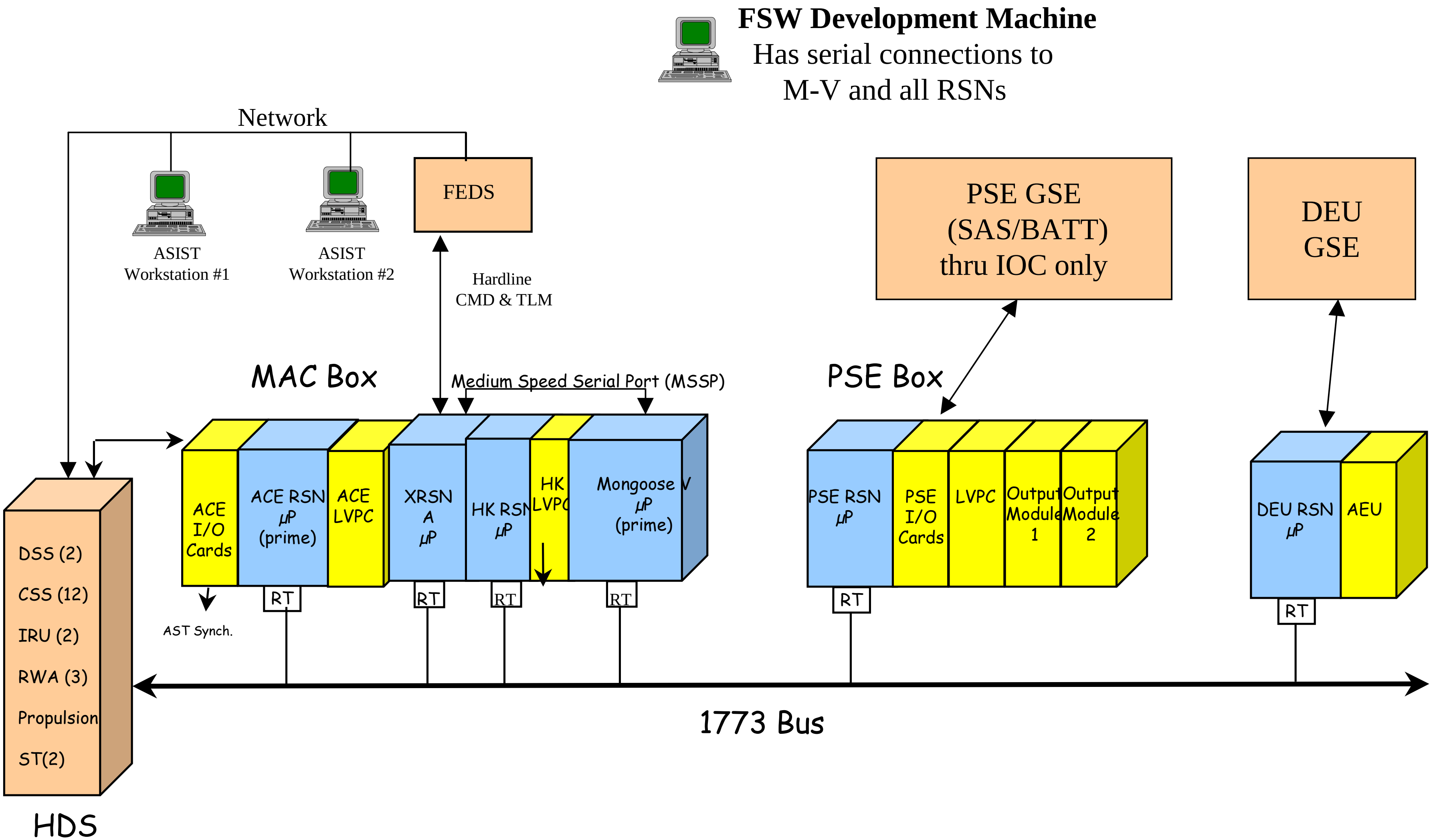


Table Maintenance

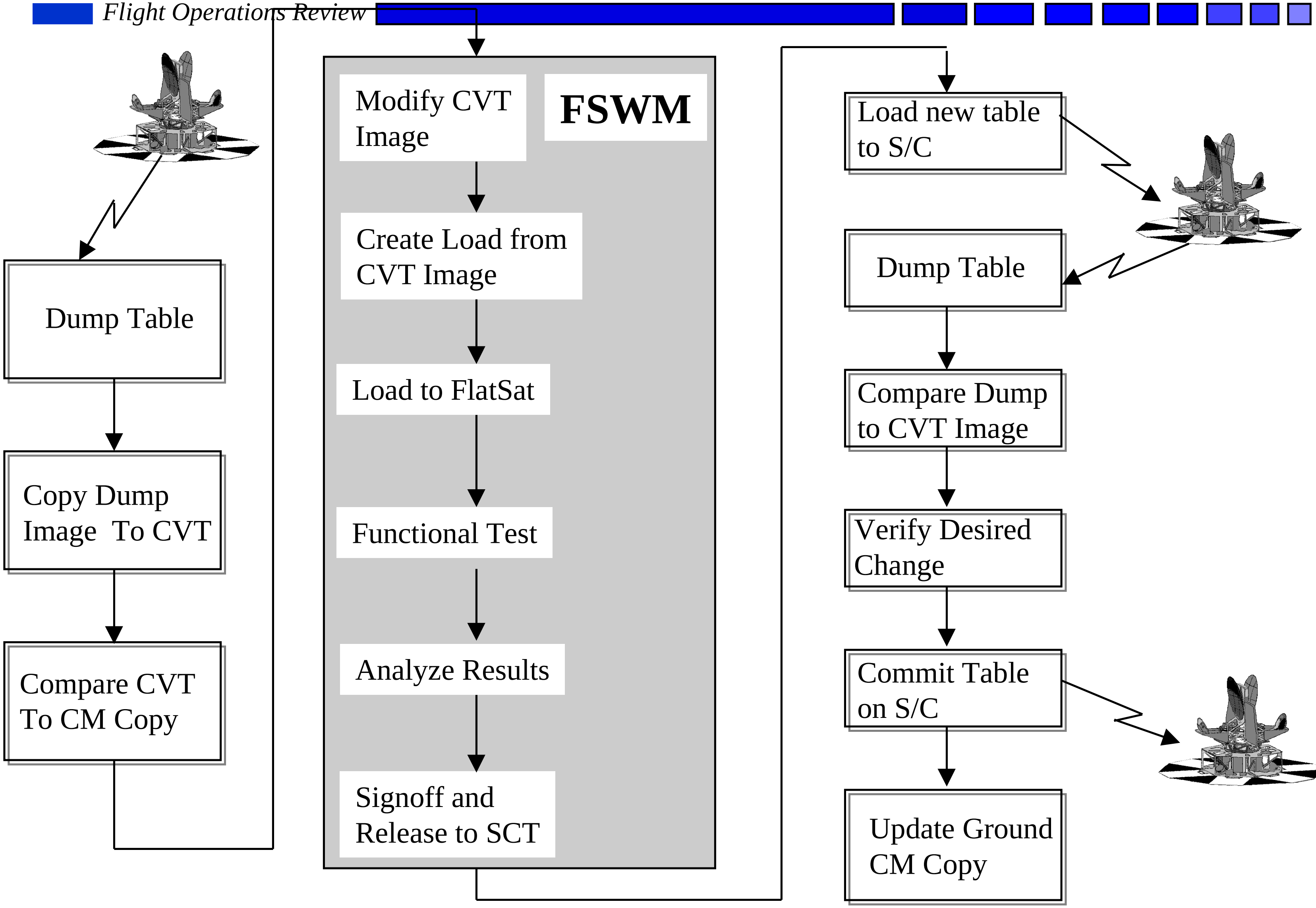


Image Maintenance

• All tables and images will be dumped prior to launch as a baseline for future modifications. Files kept in CM. (Ownership of files and details of CM shall be worked out in FOT ICD and FSW Maintenance Plan).

• Patches will be coded and tested by maintenance team prior to uplink.

• Reference images and patches kept in CM

• All changes to software will be tracked via the Maintenance team CM system

• All changes to software must be brought before the Configuration Control Board (CCB) for approval

Conclusion

Steven Coyle

Conclusion

- Action Item Review
- Panel Caucus
- Panel Evaluation

RESPONSES TO RFA's FROM THE
MAP FLIGHT OPAERATIONS REVIEW

RFA #1

ACTION REQUESTED:

Determine the impact and do risk mitigation in case the existing rate 1/4 Viterbi decoders fail. This is requested from both the DSN loading point-of-view and the Project point-of-view. Get a commitment [or estimate] from JPL as to how long the DSN will be able to support Viterbi decoding for MAP and a recommended strategy if support is lost.

SUPPORTING RATIONALE:

The rate 1/4 Viterbi decoders are required for the processing of the 666-kbps downlink with margin. Concern was expressed that there are no JPL plans to replace failed units due to lack of money.

PROJECT RESPONSE:

1) BLOCK III MCD BACKGROUND INFORMATION

The Block III MCD is a large, multi-layer, very [component] dense, and extremely complicated device. As it turns out, the DSN now has three operable units at each complex. The DSN also has a number of additional units, which are in some mode of failure; the DSN has put much effort into attempting to restore the additional units to an operational state, but has so far been unsuccessful. We are still attempting repairs of the failed units, but the chance of success is really quite problematical. The situation is further complicated in that the original vendor of this equipment is no longer in business.

TMOD has concluded that these devices must eventually be phased out of the DSN. No further units can be or will be purchased, or developed by the DSN. Ultimately, it is expected that Turbo Codes will replace the Block III MCD capability, although the current design and plan for Turbo Codes [expected in 2003] is [for] a data rate of only 250 Kbit/s [with a possible extension to 350 Kbits/s]. The current plan is to have these devices [Block III MCDs] entirely phased out of the operational DSN by 2009. Until that time, they have been committed to a number of Projects being supported by the DSN.

2) THE DSN BLOCK III MCD COMMITMENT TO THE MAP PROJECT

The DSN made the following formal commitment to the MAP Project requirement for MCD Block III capability, in the MAP DMR:

"ACCEPTED WITH QUALIFICATIONS. THE BLOCK III MCDs ARE A LIMITED RESOURCE AND SUBJECT TO AVAILABILITY."

The point of the above being, that the MAP Project has been on formal notice for several years now, that the BLOCK III MCDs are a somewhat iffy proposition, and that TMOD was not in any way making an *unconditional* guarantee to provide this capability. Should the MAP Project find that Block III MCD capability is either partially or entirely lost, the onus is on the Project to find an adequate work around. Of course, the DSN will do everything in its power to assist the Project, in such an eventuality. Again, under no circumstance should this situation be considered a *surprise* at this very late juncture!

3) OTHER RELEVANT FACTORS

As previously mentioned, the Block III MCDs have been committed to a number of other Projects, out to 2009. Among these Projects are those in the NASA *battleship class* [NASA investment of greater than 1 Billion dollars], such as CASSINI, SIRTF, and the Mars Program. Not to in any way minimize MAP, but in the event of a partial or complete loss of Block III MCD capability, the impact to TMOD/JPL/NASA of CASSINI, SIRTF, and the Mars Program, will completely dwarf and out shadow the MAP Problem. Again, not to in any way denigrate or minimize the importance of MAP, but, it is clear that far larger, far more visible, far more costly NASA Projects will drive any and all actions in the event of serious problems with the Block III MCDs! This doesn't mean that MAP doesn't have to think about [and do some planning for] workarounds and alternatives [as we have done in item 3) above], but that in the eventuality of [serious] Block III MCD problems, the *battleship class* NASA missions will *carry water* for *all* other DSN Block III MCD users, and, very definitely included in that set of *other* Block III MCD users, MAP!

RFA #2

ACTION REQUESTED:

Show the activity timeline, including contingency actions, for Day 1 after launch. Identify timeline margins to allow for unexpected spacecraft and ground system problems. Re-evaluate the rational for Day 1 check out activities

SUPPORTING RATIONALE:

Day 1 activities are extremely ambitious and may include non-mandatory activities that could introduce unnecessary delays and complications

PROJECT RESPONSE:

The comment regarding Day 1 activities as being "extremely ambitious" is absolutely correct. The project philosophy for day one is to successfully meet three primary objectives: 1) Separate and achieve a power positive attitude, stable on the sunline, 2) Unload Checkout – incase of high tip-off rates, unload momentum to zero, 3) Safehold Checkout – be sure that safehold functions incase of autonomous safehold. Another pacing objective is that all critical ACS verification and calibration operations must be executed within the first six days (first perigee maneuver is on day 7).

The actual nominal aggregate procedure runtime for all Day 1 operations is under two hours. The plan is to perform all Day 1 operations during the 9 hour pass with Goldstone right after launch. This allows 7 hours between procedures for data analysis, spacecraft performance monitoring and contingency resolution.

As a part of our Mission Sim #2 the MAP team ran through all Day 1 operations within the allocated timeframe with unplanned contingencies introduced. In realtime, the team responded to FDC misconfigurations, loss of comm, loss of voice and a Delta-H ACS mode anomaly. And the team successfully completed all Day 1 ops.

The MAP team will keep the existing Day 1 activities as our baseline. At the Delta FOR we will present a minute-by-minute timeline of all Day 1 activities. The team will continue to exercise Day 1 ops as part of our Mission Sims and gain more confidence in our plan. Also, Day 2 has nearly full ground coverage and any incomplete Day 1 activities could be moved into Day 2 with little or no impact.

RFA #3

ACTION REQUESTED:

Clarify what spacecraft data (and other products) are stored on the 500 Gb jukebox in the SMOC that do not go to the OMEGA. OMEGA should get all spacecraft data. Secondary products (i.e., derived products) should be systematically review for inclusion.

SUPPORTING RATIONALE:

The answer to this was not clear at the review

PROJECT RESPONSE:

Data to be Stored on the DHDS in the SMOC

All spacecraft data received will be archived on the DHDS. This includes all processed real-time and recorder playback data which is stored at the VCDU level. In addition, raw data files received from JPL's CDR via ftp will be stored (these files are formatted at the SFDU level).

Monitor data received from the DSN stations will also be archived (these are 1500 byte packets received once every 5 seconds during station support activity).

Raw Radio Metric data received from the DSN stations will also be archived (these are standard 1622 byte NASCOM blocks received once every 10 seconds).

Command Echo data received from the DSN stations will also be archived (these are standard 1622 byte NASCOM blocks received per command blocks sent from the control center).

ASIST logs, data archives, and trending data generated will be archived.

Orbit products generated will be archived.

DHDS Required Disk Space

The data recorded on the DHDS from the spacecraft and DSN should not exceed 300 megabytes per day and total 219 gigabytes for a 2year mission.

Data to be transferred to the Office of the MAP Experiment General Archive

All data specified in the Microwave Anisotropy Probe (MAP) Science and Mission Operations Center (SMOC) to Office of the MAP Experiment General Archive (OMEGA) Interface Control Document (ICD) will be transferred. This includes all level zero processed science and spacecraft data. Predictive and definitive ephemeris will be transferred in ASCII format.

RFA #4

ACTION REQUESTED:

MO&DA operations should be supported by a well defined and budgeted sustaining engineering and maintenance plan.

SUPPORTING RATIONALE:

Availability of MAP unique expertise may be required for time critical problem resolution or normal operations. Documentation of the requirement for there resources should ensure that the appropriate support is available for MAP

PROJECT RESPONSE:

The project has a signed MOU with Code 582, the Flight Software Branch, delineating the funding and level of on-orbit FSW maintenance support. The project also has an approved MO&DA plan and budget which delineates the funding and support levels for: science and flight operations, ground system hardware and software maintenance, science data analysis, navigation support and software licenses. The MO&DA plan has been presented to and reviewed by the Space Science Operations Project Office, Code 444.

This RFA is well taken and has prompted the project to write a general support MOU with the Applied Engineering and Technology Directorate, Code 500. The MOU will outline not only the level of support planned for In-Orbit Checkout (IOC), but it will also commit support for long-term trend analysis of on-orbit subsystem performance, L2 stationkeeping and support of contingencies. This MOU will be completed by the Delta FOR.

RFA #5

ACTION REQUESTED:

Demonstrate by analysis or a simulation that the expected stationkeeping maneuver accuracy at L2 (including OD errors) is consistent with requiring only four maneuvers per year within the allocated fuel budget, including concurrent momentum dumps and lunar shadow avoidance maneuvers.

SUPPORTING RATIONALE:

There is a negative impact to science and mission operations if more frequent maneuvers are required. Analysis to date has not included the impact of lunar shadow avoidance maneuvers.

PROJECT RESPONSE:

The trajectory team will expand on the stationkeeping analysis already completed to include the impact of momentum dumping and shadow avoidance maneuvers. The analysis will be conducted and simulated using a Monte Carlo statistical analysis.

RFA #6

ACTION REQUESTED:

For pre-launch analysis, develop a strategy to more completely investigate dispersions (most specifically, launch and Pf maneuver). A statistical analysis is recommended, such as Monte Carlo with one or more nominal trajectories.

SUPPORTING RATIONALE:

The current strategy (three trajectories per day of the launch window: one reference, one @ + 3 sigma, and one @ - 3 sigma where the +/- 3 sigma solutions include only velocity magnitude errors) is not adequate to guarantee that trajectories that satisfy all mission requirements are available for all dispersions and within the fuel budget.

PROJECT RESPONSE:

The MAP team has decided on two methods of attack to tackle this suggestion, parametric analysis and a simple Monte Carlo. The parametric study will examine the effect of TTI Delta-V variation over the -3-sigma through +3-sigma range on the required perigee maneuvers —P1,P2 and P3 —to calculate the Delta-V to get back to the same nominal trajectory. This will be done on a sampling of trajectories and will provide insight into the stability of the phasing loop trajectories based on variations in TTI Delta-V. Most notably, it will alleviate the concern that a 1 or 2-sigma Delta-V may be worse than a 3-sigma situation.

The Monte Carlo analysis to be conducted will be based on discussions that the Project and GNCC senior consultants have recommended as meeting their concerns and needs. The goals and purpose of the Monte Carlo analysis has been outlined to the trajectory team and we will begin the analysis after confirmation of our understanding from the MAP Project.

RFA #7

ACTION REQUESTED:

Identify options to increase the Delta-V margin. Select options that optimize performance and the fulfillment of key requirements. An example option is to reduce the launch period and the launch window to recover Delta-V. Another possibility is to reduce the amount of lunar shadow avoidance.

SUPPORTING RATIONALE:

The 18 m/s Delta-V margin is inadequate for a mission as complex and fuel constrained as the MAP mission.

PROJECT RESPONSE:

The trajectory team designs the trajectories using the criteria of minimizing Delta-V, but we are also required to meet mission requirements and constraints. To address this question, we can only identify constraints that cause potential Delta-V increases that we deem are areas for consideration for change. There are two requirements that are worth examination. These are the Delta-V amount set aside for the expansion of the launch window and the lunar shadow avoidance requirement in the Lissajous. We allocate 10m/s for launch window expansion. The potential impact of removing the launch window Delta-V allocation is that we may loose some launch opportunities and/or may necessitate instantaneous launch windows. The fuel budget has 20 m/s reserved for lunar shadow avoidance at L2. If MAP can accommodate the maximum 11 percent shadow expected at L2, the 20 m/s currently reserved for avoidance would be available as margin. Totaling these two suggestions adds an additional 30 m/s to the current 18 m/s margin for a total margin of 48 m/s.

We should also re-examine how we've calculated the current Delta-V budget, because the overly conservative approach may have produced a greater than 3-sigma Delta-V budget.

RFA #8

ACTION REQUESTED:

Verify that the applications software written by the maneuver team can be maintained by more than one member of the team (i.e., that more than one member be familiar with the specific code, its algorithm/s and the particular COTS package/s), which run the code.

SUPPORTING RATIONALE:

It is necessary to guarantee that the software maintenance support be available if the lead for the software is not available due to sickness, vacation, etc.

PROJECT RESPONSE:

For each of the software applications we have assigned a members of the maneuver team as prime and backup. The prime and backup are both expected to be able to maintain the given application. For COTS software this means understanding the mechanism of how to inform the vendor of discrepancies. For Goddard developed code this means actually being able to modify and maintain the application.

All software applications used in support of maneuver operations will be thoroughly tested and frozen on January 15, 2001. We do not anticipate accepting any software upgrades to the applications for the duration of the mission.

The attached spreadsheet lists all software functional applications and identifies the prime and backup team members. The spreadsheet also shows our cross training plan for the maneuver software during each of the upcoming Mission Sims. This is an attempt to make our bench even deeper beyond just a prime and backup. These team members will be trained primarily in the execution and operation of the application.